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The barite industry in the United States

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THE BARITE INDUSTRY IN THE UNITED STATES

BY

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PREFACE

Within the past few years, barite has become one of the most important non-metallic substances mined in the United States, as expressed by the large increase in production since 1943. The purpose of this treatise is to combine in a single volume important information concerning the geographical distribution, geology, mining methods, milling or beneficiation methods, production and utilization of barite in the United States. A large number of references has been used in preparing this treatment. The information has, as far as possible, been brought up-to-date. It is thought by the writer that the paper will present to the reader a complete picture of the industry as it presently exists.

This work has been made possible by a fellowship at the University of Missouri School of Mines and Metallurgy. This fellowship is named the Shell Fellowship and is sponsored by the Shell Union Oil Corporation. The writer is grateful to both the Shell Oil Company and the School of Mines for receiving this fellowship. Further acknowledgment is made to the many state geological surveys for the information received from tham at the request of the writer. In addition, the writer wishes to express his sincerest thanks to the staff of the Department of Mining Engineering at Missouri School of Mines and Metallurgy, in particular Dr. J. D. Forrester, Chairman of the department, for their invaluable advice and aid in the writing of this treatise.

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Barite is a heavy, relatively soft, opaque to translucent mineral. Its chemical formula is $BaSO_4$ and, when pure, it contains 65.7 per cent BaO, and 34.3 per cent SO_3. Barite crystallizes in the orthorhombic system, has a specific gravity ranging from 4.3 to 4.6 and a hardness of about 3.0. It is normally white, or a shade close to white, but in some places the mineral occurs as light blue crystals.

There are several forms of the mineral. For example, Kraus [1] states: "Tabular and prismatic crystals are very common, usually well developed; often complex. Tabular crystals may be arranged in crested divergent groups. Also in cleavable, granular, fibrous, or reniform masses; sometimes lamelar, nodular or earthy."

Barite is known in many localities as "barytes", "heavy spar" and "tiff". The latter term is used extensively in the state of Missouri, while in Georgia, Tennessee, and other areas the mineral is commonly termed "barytes" (bar-i-tease). "Spar" is a miner's term referring to many of the non-metallic, cleavable minerals. Therefore, "heavy spar" is used for barite since it is by far the heaviest of the spar minerals.

History

Barite was first studied in 1602 by a shoemaker in Bologna named Casciorolus. He discovered that barite becomes phosphores-

[1] E. H. Kraus, W. F. Hunt and L. S. Ramsdell, Mineralogy, 3d Edition. New York, McGraw-Hill Book Co., 1936. pp 307-308.

cent when heated with combustible matter, and gave it the name "lapis solis" or "sun stone". This was the first of the barium minerals to be examined. In 1750, Marqgraf showed that barite is a sulfate, and subsequent work by Scheele and Gahn proved that it also contained a previously unrecognized earth, which Bergmann called "terra ponderosa" or "heavy earth". In 1779, Guyton de Morveau proposed the name "barate", which is a Greek word meaning "heavy", for this earth, and Lavoiser modified the word to "baryta". (2)

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(2) Barite and Barium. Encyclopedia Americana, 1948 Edition, Vol. 3 pp. 252-253.

A detailed account of the history of the barite industry in the United States will not be attempted. In many of the references listed in the bibliography of this treatise may be found such details concerning the development of barite mining in the various states. Harness and Barsigian (3) give a list of the major developments in

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(3) C. L. Harness and F. M. Barsigian, Mining and marketing of barite. U. S. Bureau of Mines, Information Circular 7345, May 1946. pp. 2-3

---

the progress of the industry in chronological order. A few of the more important events have been chosen from this list.

1845 - Barite first mined in Fauquier County, Virginia, for use as an adulterant in white-lead paints.

1850 (approx.) - French settlers 60 miles southwest of St. Louis, Missouri, discovered barite; called it "tiff" meaning white. It was mined and shipped to St. Louis for use in paint.

1892 - Second major outlet for barite. Lithopone industry began in the United States.

1901 - Production first reported in Georgia.

1903 - Production first reported in Kentucky.

1908 - Chicago Copper Refining Co. (succeeded in 1912 by Chicago Copper and Chemical Company) began making barium chemicals at Blue Island, Ill.

1914-16 - First washers and jigs installed in Georgia and Tennessee.

1914 - Barite and witherite first mined near El Portal, California by Barber Chemical Company for manufacture of barium chemicals in San Francisco. (Not the same mine now worked by National Lead Company.)

1916 - Thompson-Weinman and Co. opened grinding plant at Cartersville, Georgia.

1923-24 - First washer installed in Missouri.

1926 - Third major market for barite: Stroud patented its use as a mud weight in rotary well drilling, and the National Pigments and Chemical Company, now the National Lead Company, put "Baroid" (ground barite for well drilling) on the market.

1928 - First use of barite as a flux in window and container glass.

1941 - Magnet Cove Barium Co., Malvern, Arkansas, separated barite from associated minerals by flotation.

USES OF BARITE

Barite is an important nonmetallic mineral; the major use of barite today being its application as a weighting material in the preparation of oil well-drilling muds. For this use, barite must be finely ground (95 per cent minus 325 mesh) and this fact presents the most troublesome problem in the industry. Ground barite is also utilized in the manufacture of glass and as a filler in many materials, such as rubber, linoleum and paint. The introduction of barite into the drilling mud business in 1926 greatly increased the importance of the mineral from the standpoint of production and consumption. With the exception of the period of the depression, 1930 to 1934, the total consumption of barite has steadily increased since 1926. In 1946, the production of barite had more than tripled the tonnage produced in 1925. None of the 1925 production was used in the preparation of drilling muds while in 1946, between 50 and 55 per cent of the country's barite production was utilized as a mud-weighting material. It is obvious that the utilization of barite as a drilling medium is, in a large part, responsible for the increasing importance of barite and the degree of attention which has been shown the mineral since 1925.

Drilling Mud

It is thought desirable to first give some basic facts concerning drilling muds in general so that a discussion of the use and value of barite in drilling muds might be made more clear.

The increase in depth of oil well drilling which has enabled a greater annual petroleum production and the establishment of more reserves, is due to the scientific advances in the art of drilling. Among these advances, the greater knowledge of drilling muds (or fluids), and their application, which has been the result of intense research, has been of major significance. The employing of some sort of drilling fluid dates back to at least 1901.[4] During the

[4] J. A. Pollard and A. G. Heggem, Mud laden fluid applied to well drilling. Bureau of Mines Technical Paper 66, 1914. pp. 5-6

early days, native clays were mixed with water to provide the desired fluid. Progressive investigations soon revealed that some clays might serve better than others for certain conditions encountered. In more recent years, research has shown that certain minerals and prepared chemical compounds will give the fluids several desirable qualities. Therefore, with scientific study of the conditions encountered and with a knowledge of the effect of the different components used in drilling muds, engineers may control the admixtures of mud by the addition of the material or materials which will give to the mud the qualities needed to successfully meet the problems encountered.

There are many functions of a drilling mud. All of these functions are not exerted at any one given time and not all are necessary in any one drilling operation. As stated in the above paragraph, the qualities necessary in a drilling mud change during the drilling of a given well and are different to some degree in every locality. Some of the more important functions may be listed as follows:

1. To support the walls of the hole being drilled, thereby preventing the caving of the hole.

2. To prevent, by the weight of the column of mud in the hole, the high pressure gas and petroleum from rapidly escaping when the reservoir rock or producing sand is tapped.

3. To float the cuttings produced by the drilling to the surface. This is accomplished because of the heavy weight of drilling

muds enabling the lighter cuttings to float to the surface. Since this action must take place rapidly, a high mud circulation velocity must be used to obtain a lift on the cuttings by the mud. The removal of a great majority of these cuttings is effected by a simple screening operation. The mud may then be reconditioned and returned to the hole.

4. To seal the walls of hole when unconsolidated material is met to prevent the loss of the mud. This is done by virtue of the gelling qualities which may be provided in the mud.

5. To hold the cuttings in suspension when drilling (and thus the circulation of the mud) is temporarily stopped. This function also relies upon the gelling property of the mud.

6. To lubricate and cool the drilling tools by coating the cuttings and thereby lessening abrasion.

Stern [5] gives the following five general classes of materials used in drilling muds: (a) weighting materials; (b) thixotropic colloids; (c) inerts; (d) chemical conditioning materials; (e) miscellaneous components.

"By definition, thixotropy refers to the property exhibited by some gels of becoming fluid when agitated. The change is reversible and occurs without alteration of temperature." [6] Thixotropic colloids when added to the mud, should give the resulting mix a great

(5) A. G. Stern, Role of clay and other minerals in oil-well drilling fluids. Bureau of Mines, Report of Investigation 3556, February 1941. pp. 51-52.

(6) Ibid, p. 56

increase in viscosity and gel strength, with a negligible increase in weight. Bentonite is the principal material used for this purpose. Inerts merely add bulk to the drilling fluid without appreciably changing the weight or viscosity of the mix. Chemical conditioning materials serve many purposes, foremost of which is to reduce viscosity. Many conditioners act as flocculators or deflocculators. Miscellaneous components include those materials added to give the fluid qualities for performing certain special functions.

Barite is by far the most widely used weighting material. Other minerals and prepared substances have been considered (some of these actually having been put to use), but none have yet met all of the desired properties as satisfactorily as has barite. Substances used for weighting purposes should increase the "mud weight" (density) without a perceptible change in the thixotropic colloids. Weighting materials should be neither corrosive, toxic nor soluble. Since the "mud weight" or density depends upon the water-to-solids ratio used in the mix and upon the density of the substance used as a weighting material, it is, of course, necessary for the substance to have a relatively high specific gravity.

DeVaney and Shelton (7) have shown in their investigation of

(7) F. D. DeVaney and S. M. Shelton, Properties of suspension media for float-and-sink concentration. U. S. Bureau of Mines, Report of Investigation 3469, September, 1939. 23 p.

materials used in sink-and-float media, that as the solids are added to the media, a steady increase in the density of the medium occurs with little apparent viscosity increase. At a certain point, however, the viscosity suddenly begins to increase in large increments with only slight increase in the density of the medium. This is also true of drilling fluids, since a drilling fluid is similar to heavy-media suspensions. This fact is stated here to show that close control must be maintained when barite (or other weighting material) is added to a mud, for a quick jump in viscosity may result from only a small addition of material. Figure 1. is taken from DeVaney and Shelton's report and illustrates this phenomenon by means of a graph of several materials tested.

As mentioned above, other materials have been considered for use as weighting materials. Among these, are iron oxide, pulverized iron, silica flour and lead. Barite has obvious advantages over these substances since it is relatively cheap, inert, colorless (does not stain as, for instance, iron oxide) and has a higher specific gravity than one, silica flour. To enable the barite to stay in suspension at the circulating velocities used, it must be finely ground. However, it must not be so finely ground as to approach the properties of a thixotropic colloid. This grind is commonly specified as 95 per cent minus 325 mesh. The barite must also have a specific gravity of over four, 4.2 being a normal field specification, and should contain little or no soluble salts. Calcium sulfate, although only slightly soluble, is included as a soluble salt since even in small amounts, it will flocculate the bentonite contained in the mud.

The ground barite used in the oil fields is usually sacked in 100 pound bags and sold by the producer to a distributor who is located close to drilling activity. The actual mixing of the muds is done at the drilling site where a certain number of sacks of ground

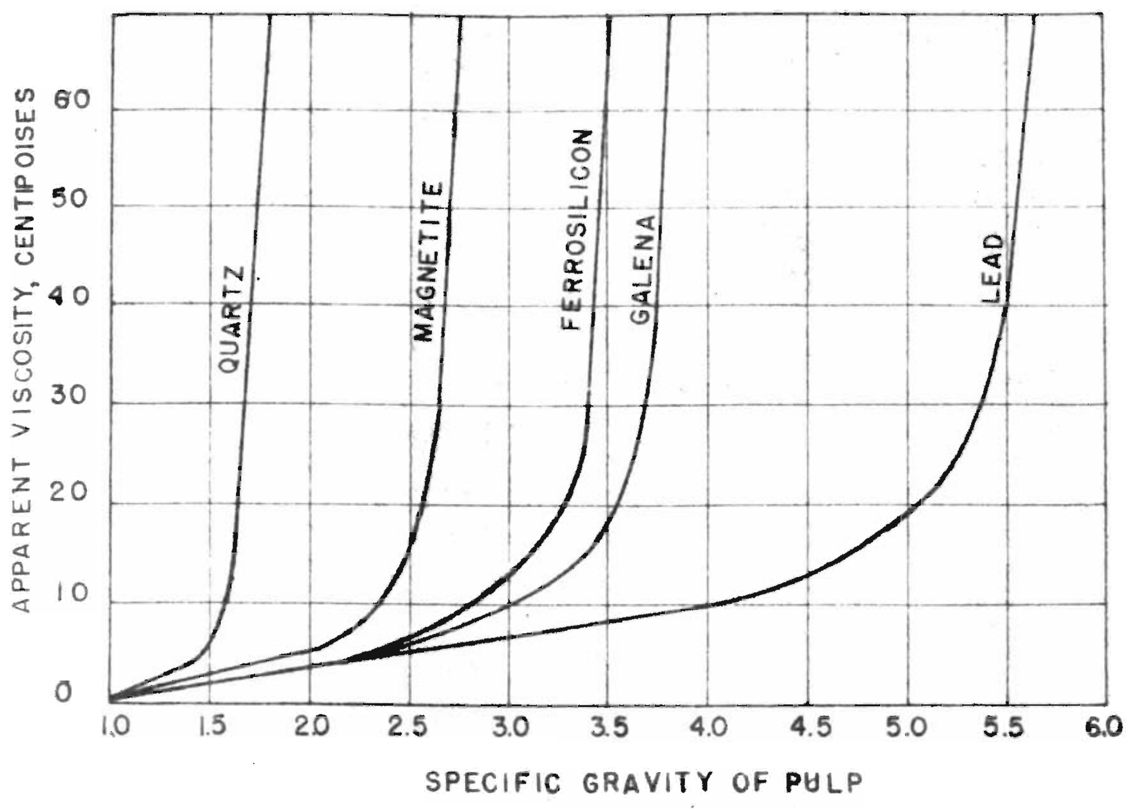

FIGURE I. Effect of specific gravity on the consistency for several suspensoids. (after De Vaney) barite is combined with the other mud constituents depending upon the conditions.

The barite employed in the drilling fluids has, in the past, been left in the slush pits with the rest of the material in the mud at the conclusion of the drilling operation. However, in recent years much attention has been placed upon the possibility of reclaiming this barite. How much of this work is now being done in the field and the degree of success resulting is unknown by the writer. Some investigation to obtain information concerning the success of such endeavors has not met with any satisfactory conclusion. A summary of a paper given by Charles A. Lindsay [8] describes one

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[8] Charles A. Lindsay, Recovery of barite from rotary drilling mud by centrifugal separation. The Oil and Gas Journal, Vol. 45, No. 23, October 12, 1946. p. 91.

---

process which has been tested.

Lithopone

Lithopone is a white paint pigment consisting of an equimolecular mixture of 70 per cent barium sulfate and 30 per cent zinc sulfide. A pigment termed "high strength lithopone" is produced containing 60 per cent zinc sulfide but in the strictest sense is not true lithopone as an equimolecular relationship between the components is not present. Previous to the application of barite to the drilling mud industry, lithopone was the leading market for barite. At the present, lithopone production is the second largest outlet for the barite produced in the United States.

The pigment is actually an intimate mixture of the two salts produced by precipitating them together. The precipitation of the insoluble compounds takes place after combining two liquids, barium sulfide and zinc sulfate. Each of these liquids is produced by carefully controlled processes. Such control is necessary to prevent the inclusion of any quantity of impurities in the final product. The zinc sulfate is obtained by successively roasting sphalerite to an oxide, obtaining impure zinc sulfate by treating the oxide with sulfuric acid, and finally a pure zinc sulfate liquor is evolved after treating the impure sulfate with zinc dust.

The barium sulfide liquor is produced from barite concentrate as follows: The barite is reduced to a size range of 10 to 100 mesh by crushing and grinding. This ground product is then introduced to a rotary kiln along with coal which has been reduced to the same particle dimension. The usual combination ratio is 100 pounds of barite to 20 pounds of coal. The material discharged from the kiln is in the form of black granules or cinders termed "black ash". Theoretically, this black ash is barium sulfide, but actually it consists of impurities of carbon, unreduced barium sulfate, and non-volatile matter originally contained in the barite concentrate and in the coal. Harness and Barsigian [9] state that "BaS comprises only 75 to 85 per cent of the total." The barium sulfide is leached from the black ash, even though barium sulfide is quite insoluble. This is possible since barium sulfide hydrolyzes readily, producing $Ba(OH)_2 + Ba(SH)_2$. This is termed "barium sulfide leach liquor" and is the liquid which is actually combined with the zinc sulfate

(9) C. L. Harness and F. M. Barsigian, op. cit., p. 25.

solution. The addition of the latter to the barium sulfide leach liquor produces a reversal of the hydrolysis action and practically all of the sulfide ion is combined with the zinc, forming insoluble zinc sulfide.

Heaton [10] gives the following description of the precipitation of the pigment: "The precipitation of the pigment is effected by running the barium sulphide solution into a vat and adding the zinc sulphate, slowly with constant stirring, until it is in slight excess. The precipitate formed is collected and washed in the usual manner, and dried at a low temperature to avoid oxidation of the zinc sulphide. The material in this state forms a very indifferent pigment, and the great feature of Orr's (the discoverer of the lithopone process) invention was the subsequent process by which the pigmentary properties are developed. This consists of charging the dried precipitate into closed retorts, which are heated to bright redness, care being taken to exclude access to air. Whilst red hot, the contents of the retorts are discharged into cold water. The pigment is then thoroughly ground whilst wet, and finally filter-pressed and dried once more." Heaton also includes a sample range of composition of lithopone, taken from analysis of a number of samples.

Moisture	0.06 to 0.35	per cent
Soluble salts and impurities	0.08 to 1.50	" "
Zinc oxide	0.30 to 2.96	" "
Zinc sulphide	23.10 to 29.36	" "

(10) N. Heaton, Outlines of paint technology. London, Charles Griffin and Co., 1928. p. 90.

Barium sulphate .... 67.43 to 75.41 per cent

Lithopone does not compare favorably with several other white pigments, especially titanium dioxide, with regard to hiding power (that is, the opacity of a paint, which is specifically the ability to reduce the contrast of a black-and-white surface to which it is applied). Lithopone continues to stay in competition primarily because of its lower price of manufacture. Its consumption, however, has declined slightly during the past few years. In addition to lower hiding power, lithopone also has a characteristic unique among pigments of being darkened upon exposure to ultra-violet light, which limits its use for exterior paints. Therefore, lithopone finds its greatest utilization as a pigment for interior paints.

Specifications for barite employed in the manufacture of lithopone vary somewhat among the different buyers, and are also affected by the supply available. In general, however, they may be stated as being 94 per cent minimum $BaSO_4$, and one per cent maximum Fe_2O_3. A bonus and penalty system is sometimes engaged for greater and lesser amounts of these compounds.

Figure 2. summarizes "crude" lithopone production with the use of the flow steps given by Mills.[11] It is called to the reader's

(11) H. Mills, Characteristics of lithopone and zinc sulfide pigments for paint manufacture. Chemical Industries, Vol. 38, No. 5, May 1936. p. 481.

attention that the product shown as resulting from these flow steps has no marked pigmentary properties. The finished product with the properties necessary for a good pigment is the result of the calcining procedure as outlined above. This heating and sudden cooling of

"CRUDE" LITHOPONE PRODUCTION

(After Mills)

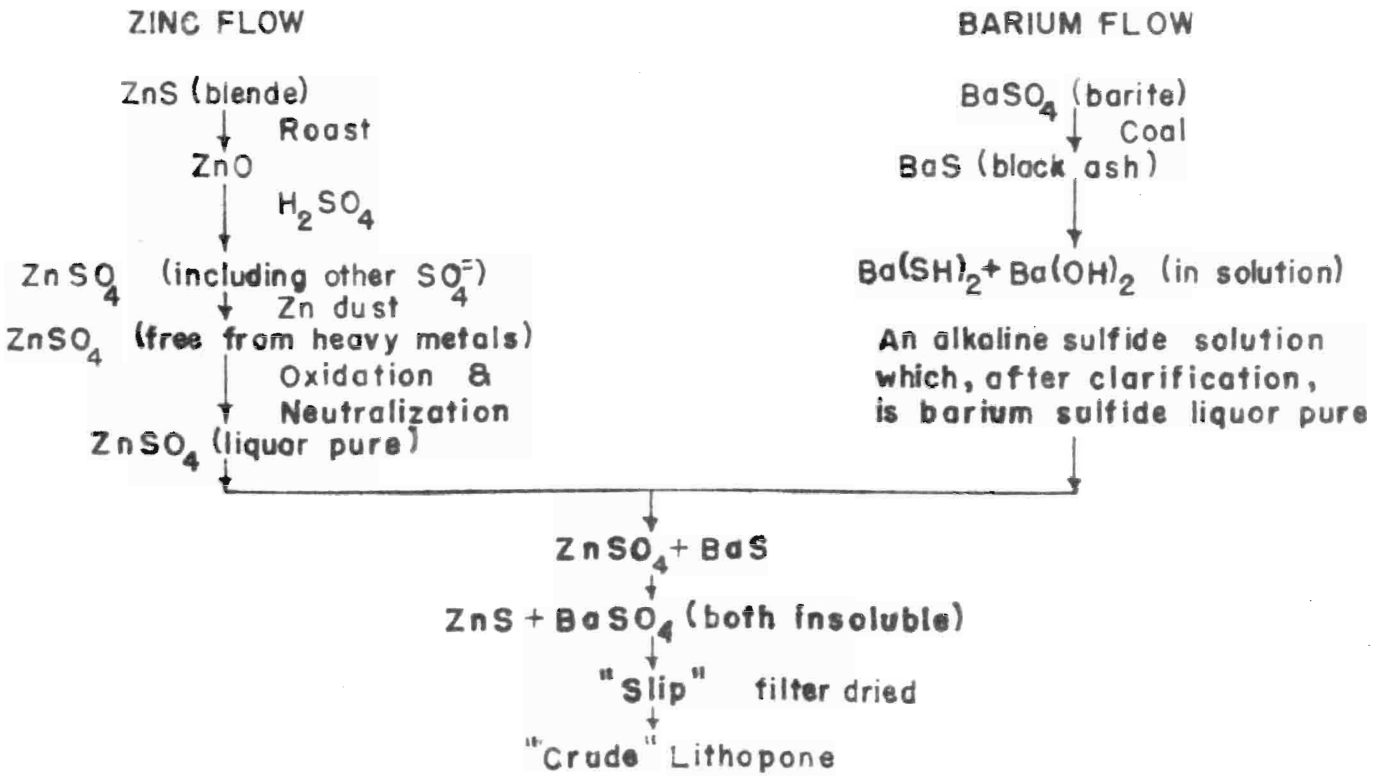

FIGURE 2.

the crude lithopone causes an increase of the refractive index, and therefore the opacity. Such calcination also functions to "convert both the zinc sulphide and the barium sulphate from the amorphous to the crypto-crystalline condition and to form an intimate combination between the two".[12]

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(12) N. Heaton, op. cit., p. 90.

Barium Chemicals

The manufacture of barium chemicals ranks third as an outlet for barite production with regard to tonnage consumed. The following are the barium chemicals produced in 1946 as listed in the U. S. Bureau of Mines Minerals Yearbook of that year: black ash (sulfide), carbonate, chloride, hydroxide, nitrate, oxide, peroxide, sulfate (synthetic), and others.

The principal consideration in producing barium chemicals from barite is the converting of the slightly soluble barite to a water soluble compound. Many processes have been patented for this conversion and some have been tried on a commercial scale. None, however, have attained success, and the present methods used are all based on the obtaining of black ash as a starting point.

An explanation of the manufacture of each of the barium chemicals produced will not be given. An excellent discussion may be found in the paper by Harness and Barsigian.[13] The uses of each of the chemicals produced is also given in this paper. The following uses mentioned are a few of those given in that reference.

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(13) C. L. Harness and F. M. Barsigian, op. cit., pp. 27-46.

<u>Synthetic barium sulfate or "blanc fixe"</u> is used as a base or

extender in vehicles of high refractive index (such as the usual drying oils) and as a pigment in vehicles of low refractive index (such as water paints). It may be used as a base for the precipitation of titanium dioxide for organic dyes. Blanc fixe is difficult to redisperse in water after once having been dried, and for this reason much of it is sold in a pulp containing 20 to 30 per cent water. Pulp blanc fixe is used mostly as a paper filler.

Barium chloride is used in case-hardening, as a mordant in textiles, in forming blanc fixe in place in leather and cloth, as a flux in making magnesium metal, and in numerous chemical processes.

Barium carbonate is employed to prevent the formation of scum in ceramics exposed to moisture; to diminish porosity, prevent discoloration and give a brilliant glaze to the surface, of brick. Barium carbonate is also used for case-hardening steel parts when the supply of witherite (naturally occurring $BaCO_3$) is reduced. Crown and flint types of optical glass utilize some barium carbonate.

Barium oxide and peroxide, formerly used for obtaining oxygen and hydrogen peroxide, is now employed only on a minor scale. A mixture of barium oxide and witherite is said to increase the life of the acid lining of electric furnaces when added to ferrous melts half an hour previous to pouring.

Barium hydroxide, in addition to its use in ceramics to prevent scumming (like barium carbonate and chloride), is employed to recover sugar from residual beet-sugar molasses by the Great Western Sugar Co., Denver, Colorado.

Barium nitrate is produced in wartime for use in green signal flares and in primers and detonators.

Barium metal is a satisfactory dioxidizer of copper and decreases the conductivity of the copper but little. Barium metal has a high rate of electron emission when subjected to an electrical potential so it is utilized for spark plugs and for electron-emission elements in electron tubes.

The specifications for the preparation of barite for use in chemical manufacture vary but are in general the same as those maintained for barite used in lithopone.

Other Uses

Other uses consist of ground barite consumption in glass, and as a filler in rubber, paint, ink, oilcloth, linoleum, X-ray proof fabricated walls, asbestos brake linings, and other similar materials. Together, these other uses consume but little of the United States production.

Barite is used in glass manufacture for several reasons: (a) it fluxes the heat-insulation froth that tends to form on the surface of the melt, thus saving fuel; (b) it acts as an oxidizer and a decolorizer; (c) it makes glass more workable; (d) it increases brilliance in the finished ware. A typical analysis of the barite used in glass manufacture is: $BaSO_4$, 98.0 per cent; SiO_2, 1.5 per cent; Al_2O_3, 0.15 per cent; and Fe_2O_3, 0.15 per cent.[14]

(14) Ibid, pp. 23-24; 51

Dawson[15] gives information concerning the utilization of

(15) T. R. Dawson, Barytes and its employment in the rubber industry. India Rubber Journal, Vol. 73, pp. 885-889, 926-930, 961-966.

barite in the rubber industry.

PRODUCTION AND CONSUMPTION (16)

(16) Data given below have been obtained from Minerals Yearbook 1946. U. S. Bureau of Mines. Washington, U. S. Government Printing Office, 1948. pp. 162-173.

The producers of barite in the United States sold or used 724,326 short tons of the material in 1946. This was an approximate 4 per cent increase over 1945, a 40 per cent increase over 1944 (a record production having been reported for each of these years) and a 72 per cent increase over 1943. These figures show the magnitude of expansive growth experienced by the industry in recent years. The United States leads the world in barite production, having surpassed Germany in 1940.

Arkansas led production in 1946 with 288,286 short tons at an estimated value of $1,844,982. Missouri ranked second, having mined 270,850 short tons at a value of $2,168,067. Production in Georgia was 69,274 short tons valued at $686,583 and Tennessee was fourth with 33,595 short tons marketed with a reported value of $272,169. The output from Arizona, California, and Nevada as a whole, was 62,357 short tons valued at $270,954. The total value of domestic barite sold or used by producers in the United States during 1946 was $5,242,755. Table No. 1 shows the production and value data by states for the years 1944 and 1945.

The distribution of consumption of barite (short tons) in the United States in 1946 was reported as follows: Well drilling, 372,610 or 51.6 per cent; lithopone, 154,166 or 21.4 per cent; chemicals, 102,439 or 14.2 per cent; glass, 29,181 or 4.0 per cent; paint filler, 26,000 or 3.6 per cent; rubber filler, 20,000 or 2.8 per cent; and for other purposes, 17,677 or 2.4 per cent. These figures include both foreign and domestic barite.

Table No. 1

Domestic barite sold or used by producers in the United States, 1944-45, by States

State	1944 Short tons	1944 Value	1945 Short tons	1945 Value
Arkansas	159,686	$1,045,546	260,660	$1,934,098
Georgia	108,851	929,090	110,393	1,056,035
Missouri	150,748	1,121,678	225,467	1,841,959
Nevada	22,390	84,859	28,919	106,052
Tennessee . . .	43,033	279,567	32,812	256,756
Other States . .	33,909	97,749	37,811	153,752
	518,617	3,558,489	696,062	5,348,652

The imports of barite to the United States totaled 44,662 short tons in 1946; the value of which was $274,267. Canada exported to the United States 44,109 short tons (value, $268,839) and 553 short tons (value, $5,428) were received in this country from Mexico. This import tonnage was the smallest since 1943 and combined with the domestic barite sold or used by producers in the United States gave an apparent new supply of 769,024 short tons.

The United States leads by far over the other countries in barite production (657,908 metric tons). Germany has produced much

FIGURE 3. Distribution of barite in the United States

barite and until 1915 supplied the United States with the major part of this country's consumption. In 1944, Germany yielded 320,000 metric tons; since then, no figures are available. Canada's output has been greatly increased since 1940, having risen from 307 metric tons in that year, to 109,000 in 1946. The Canadian Industrial Minerals Company has mined barite since 1941 at Walton, Nova Scotia, on the Bay of Fundy. "For the first few years, oil well drillers in Trinidad and South America were the largest outlets for production. In 1942, and again in 1944 and 1945, however, sizable shipments were made to the barium chemicals industry in the United States."[17]

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(17) Op.cit. 16, p. 167

The United Kingdom produced 94,711 metric tons (including witherite) in 1945. France, in 1946, showed a production of 26,424 metric tons. Other barite producing countries, from which figures are available, show only minor production tonnages. A table giving world production of barite by countries for the years 1940-46 may be found on page 166 of the Minerals yearbook for 1946.

DESCRIPTION OF PRODUCING AREAS

Arkansas

Location

There are two major districts where barite is known to occur in Arkansas. (1) The Magnet Cove deposit, located approximately two miles east from the border of the Magnet Cove intrusive. This intrusive outcrops as hills which form the boundary of an elliptical basin open only on the northeast and southwest where a stream enters and leaves the basin. From this shape is derived the term "cove". The barite ore body lies north of the town of Malvern, Arkansas, at a road distance of nearly 12 miles. Malvern is forty-five miles southwest of the capital city of Little Rock on U. S. Highway 67. The deposit lies wholly within Hot Spring County, of which Malvern is the county seat. Hot Springs, Arkansas, in Garland County, is some 15 miles to the west of the deposit. The area is readily accessible from Malvern by proceeding toward Hot Springs on U. S. Highway 270 to the village of Magnet, then turning northeast on an improved road for about two and one-half miles. (2) The Montgomery County deposits, located in southern Montgomery County which is in the west central part of the State. There are several occurrences in this district, the two major ones being on Gap Mountain and on Fancy Hill. The largest nearby town is Glenwood, Arkansas, which is in Pike County, 32 miles southwest of Hot Springs. Glenwood may be reached from the latter via U. S. Highway 70. The area is within the Ouachita National Forest.

Both of these locations are in the Ouachita Mountain range which extends from near Malvern westward, terminating at the Arbuckle Mountains in south-central Oklahoma. The general geology of the two areas and the modes of occurrence of the barite in each area are similar. Practically all of the barite discovered in these districts has been in the lower part of the Stanley shale formation, which is noted extensively throughout the Ouachita range. For this reason, there is an excellent chance that other deposits may be found within the range.

Because the deposits are similar, and since active mining is being carried on only in the Magnet Cove district at the present time, the description to follow will be limited to the Magnet Cove deposit.

Physiography, Topography and Climate

The Magnet Cove area, as stated previously, is within the Ouachita Mountain range which is the most southern of the two major physiographic divisions of the Ouachita Province. The division to the north is the Arkansas Valley. The primary physical difference between the two divisions is that the beds in the Ouachita Mountains have been folded into an anticlinorium whereas the beds in the valley have been folded into a synclinorium.

By further subdivision of the physiography, the Ouachita Mountains are composed of three parts: (a) the Fourche Mountains; (b) the Novaculite Uplift; and, (c) the Athens Piedmont Plateau. The Novaculite Uplift consists of seven small mountain groups and four basins, listed as follows:[18]

(18) C. Croneis. Geology of the Arkansas paleozoic area, Arkansas Geological Survey, Bulletin 3, 1930. p.7.

Caddo Mountains	Zigzag Mountains
Cossatot Mountains	Caddo Basin
Cross Mountains	Mayarn Basin
Crystal Mountains	Ouachita Basin
Northern Mountains	Saline Basin
Trap Mountains	

The Magnet Cove barite deposit is situated within the Zigzag Mountains.

The Zigzag Mountains are a group of moderately sloped ridges which trend northeast-southwest with elevations of 600 to 1000 feet above sea level. The ridges and the valleys which lie between them are the topographic expression of plunging anticlines and synclines. The tops of the ridges are formed by the Arkansas novaculite formation which is a resistant rock. Parks [19] states:

(19) Bryan Parks. A barite deposit in Hot Spring County, Arkansas. Arkansas Geological Survey, Information Circular 1, 1932. p.12.

"The small streams which drain the slopes have cut back into the ridges and formed numerous spurs and hollows. The larger streams have, in a few places, cut their courses across the resistant strata and formed rugged water gaps." The barite ore deposit lies in the Chamberlain Creek syncline, one of the small synclines in the Zigzag Mountains. In the immediate area of the deposit, the relief is not greater than 225 feet. Chamberlain Creek syncline is closed at the east end and is cut off by the Magnet Cove igneous structure at the west end. The average elevation at the upper or east end of the syncline is approximately 650 feet above sea level.

Normally, the area has mild climate. The average annual rainfall is 47 inches and the mean annual temperature is 61 degrees.[20]

(20) R. B. McElwaine. Exploration for barite in Hot Spring County, Arkansas. U. S. Bureau of Mines, Report of Investigations 3963, September 1946. p. 4

Most of the rainfall occurs during the first six months of the year. This area of Arkansas has been greatly exploited for timber and much of the land is still owned by lumber companies.

General Geology

There are three formations associated with the barite deposit at Magnet Cove. The Arkansas novaculite is the oldest of the three and underlies the barite for an undetermined thickness. The formation is named for the occurrence of novaculite, which predominates throughout the beds. Novaculite is an unusual variety of siliceous rock, being extremely fine grained in texture. Its fracture is conchoidal and its color is predominately white or light gray, although it sometimes shows red, brown or black shades. These shades are the result of carbonaceous matter or iron and manganese oxides. The composition of novaculite is over 99 per cent silica with only minute amounts or traces of other constituents. Joint patterns in the novaculite are quite complex, the major set of joints being normal to the bedding. The formation is noted throughout the Ouachita Mountains, its thickness averaging 900 feet in the south and thinning to the north rather rapidly. (21) Geologists have

(21) C. Croneis, op.cit., p. 105

placed the Arkansas novaculite in the Devonian period.

Immediately above the novaculite in the stratigraphic column, is the Hot Springs sandstone. This formation is not wide spread and is noted primarily in the vicinity of Hot Springs where it attains a thickness of approximately 200 feet. Where present, it lies discomformably on the Arkansas novaculite, and consists of thin, lenticular beds of quartzitic sandstone and shale. In the close vicinity of the barite deposit, that is, in Chamberlain Creek syncline, the Hot Springs sandstone is found only as a thin bed.

When it is present in the surrounding ridges of the Zigzag Mountains, it outcrops as thin, lenticular, steeply inclined beds. The Hot Springs sandstone is usually classified as lower Mississippian in age.

The youngest of the three formations associated with the barite deposit is the Stanley shale, of Carboniferrous, probably Mississippian age. This group of beds is widely distributed over the entire Ouachita province and attains a thickness of several thousand feet in many localities. The Stanley shale is made up of alternate beds of shale and fine-grained sandstone, the beds of sandstone usually being thin and separated by relatively thick layers of dark shale. At places, thin layers of novaculite conglomerate occur at the base of the formation. The Stanley lies as an overburden of the barite in Chamberlain Creek syncline over the entirety of the deposit, except where the barite outcrops along the limbs of the syncline.

The Zigzag Mountain group is at the eastern border of a synclinorium called the Mazarn basin, another member of the Novaculite Uplift (see page 23). The beds are folded in the Mazarn basin but this folding seldom shows expression on the surface. Where the folding of the beds rises above this level on the east marks the division of the Zigzags and the Mazarn basin. McElwaine [22] has noted a structural analogy of the two areas of

(22) R. B. McElwaine, op. cit., p. 5

barite deposition in Arkansas. "Within the (Mazarn) basin the folding of the strata does not extend much above the present erosion level, but at the extreme eastern end the folding extends above the surface to form part of the Zigzag Mountains. It is interesting to note that at the other end of the Mazarn basin, the folds within the syncline again protrude above the erosion level, and at this end of the syncline are found the barite deposits of southern Montgomery County."

The Magnet Cove intrusive which cuts Chamberlain Creek syncline at the west end, is nepheline syenite. The so-called floor of the Cove is covered by deep, residual and alluvial soil. Surrounding the structure is a zone of intense mineralization, some 50 different minerals having been identified within the five square miles included in the Cove area. Mining of several of these minerals on a commercial scale has been attempted at different times, but to date none have met with economic success. The principal interest has been shown in titanium minerals, rutile and brookite, which are found in abundance, and in a network of small veinlets of molybdenite. The titanium occurs as both primary minerals in the syenite and as contact minerals in the surrounding metamorphic rocks.

Geology of the Deposit

The barite at Magnet Cove which occurs in the eastern end of Chamberlain Creek syncline, conforms with the general shape of the syncline, which plunges westward at about 35 feet per hundred and is closed sharply at the eastern end. The deposit outcrops at the point of closure and along the limbs of the syncline. The structural axis of the syncline, and thus the axis of the deposit, trends within ten degrees of east-west.

The south limb of the deposit is considerably steeper than the north limb, although the north limb progressively steepens from the closed end westward. Therefore, the structural axis of the syncline is closer to the south limb than to the north limb. The ore extends for about one-half mile down the syncline and at this distance the outcrops of the ore body have diverged to a distance of 1800 feet. Measured in the plane of the synclinal axis, the depth of the ore at this point is 670 feet and this is the maximum depth at which the ore lies below the surface. In thickness, the deposit varies from 10 to 70 feet with an average thickness of near 40 feet. The dip of the north limb ranges from 10° near the east point to 80° at the western end of the deposit; the dip of the south limb changes in like manner from 50° to 90°.

Stratigraphically, the barite occurs at the base of the Stanley shale and is separated from the novaculite by only a thin seam of shale. In places, this bottom shale seam is absent, and a basal conglomerate consisting of novaculite boulders underlies the ore. Where the underlying seam of shale does exist, it never exceeds 18 feet in thickness and is normally much thinner. The lower border of the ore deposit is sharp, but the upper portion of the barite is gradient into the shale. A minimum barite content of about 40 per cent is necessary for the rock to be termed ore. This figure is used when it is necessary to plot the upper boundary of the ore zone on cross-sections. The ore body vanishes at both ends by a combination of thinning and interbedding with the shale.

The most commonly propounded explanation of origin of the barite deposit has been that hydrothermal solutions containing a considerable quantity of barium sulfate coming from the Magnet Cove intrusion, some two miles to the west, proceeded along the contact of the shale and novaculite and, with conditions favorable because of the closure of Chamberlain Creek syncline and a possible reduction of temperature and pressure, replaced the lower portion of the Stanley shale which was calcareous. There have been few published investigations of the Magnet Cove barite ore which have attempted to give full explanation of a possible origin of the hydrothermal solutions. However, some degree of work has been done according to Benston (23) who states: "Originally it was thought that the Magnet

(23) O. J. Benston. Barytes operations in Arkansas. Mining Congress Journal, Vol. 32, No. 6, June 1946. p. 26.

Crater had a definite bearing on the formation of this ore body, but more recent investigations tend to show it as contemporary rather than causative." It is a general belief that, regardless of the source, the barium sulfate was brought into the syncline by virtue of a solution which was the direct result of some igneous activity.

Figures 4 and 5 show a plan and section view of the deposit taken from the paper by McElwaine. (24)

(24) R. B. McElwaine, op. cit., figures 2 and 3.

Description of the Ore

The material of the ore zone is a soft, earthy rock with a

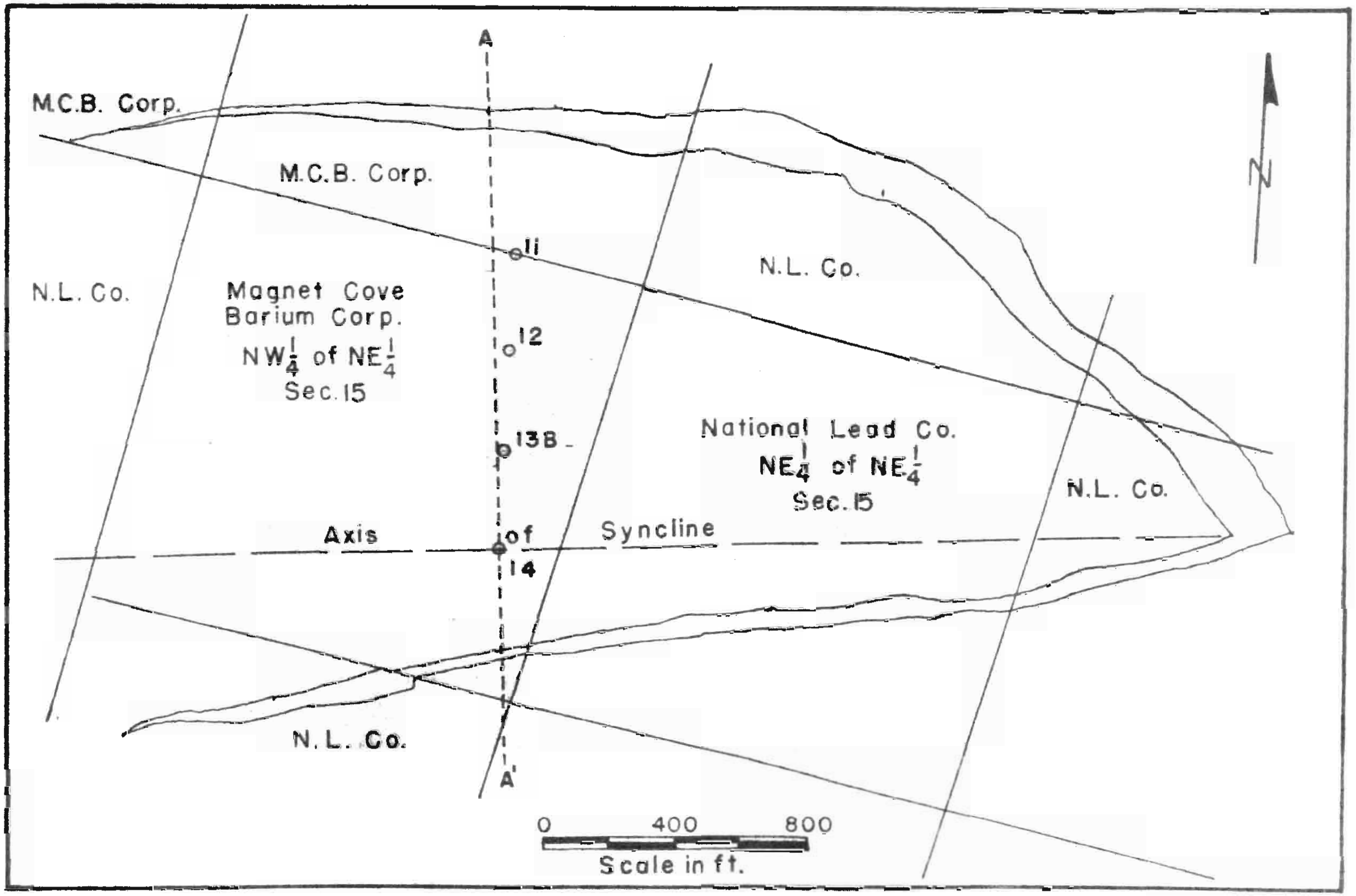

FIGURE 4. Surface exposure of Magnet Cove barite deposit (after McElwaine).

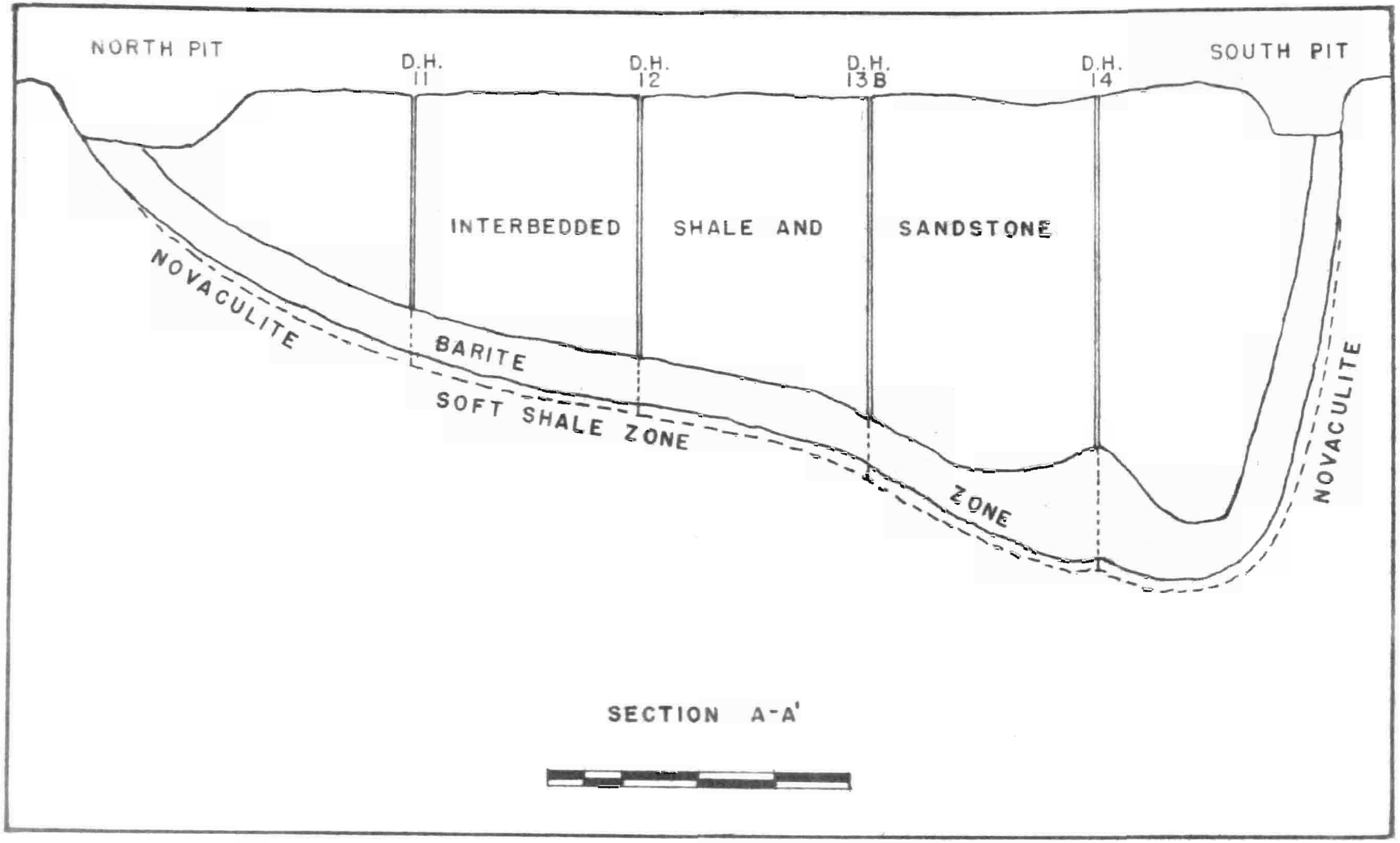

FIGURE 5. Cross-section of Magnet Cove barite deposit (after McElwaine)

definite shaley appearance near the surface. It is light gray in color with an occasional red tinge. With depth, the ore hardens, becomes more dense and its color changes to a darker gray. Some drill samples have shown that the ore from the deeper parts of the deposit resembles dense crystalline limestone.

Mineralogically, the ore consists of barite, some pyrite, silica and clay minerals, and at places, calcite. The barium sulfate content averages 65 per cent and the specific gravity of the ore has a mean value near 3.5. In the prospecting, assaying and sampling of barite or possible barite deposits in this area, the specific gravity determination is employed in preference to barium sulfate analysis. This is possible since it has been shown that a definite relationship exists between the per cent barium sulfate contained in a sample and the specific gravity of the sample.[25] The primary impurity is silica but the small amount of pyrite present which is seldom more than four per cent, presents the major trouble in concentrating the ore.

Horses or lenses of shale are present throughout the ore zone. This condition is a result of the interbedding of the barite with the shale since the barite has replaced parts of the shale, some portions remaining entirely void of replacement. Also admixed with barite in the ore zone are stringers of clay and sandstone.

[25] Specific gravity and assay relationship of Arkansas barite. Engineering and Mining Journal, September 1948, p. 91.

Mining Methods

At the present time there are two producers of barite from the Magnet Cove deposit; the Magnet Cove Barium Corporation and the Baroid Sales Division of the National Lead Company. Property ownership and leases may be noted from the plan map of the deposit in Figure 4. Magnet Cove Barium began operation in 1939 and National Lead started in 1941. Both organizations have used open pit methods in extracting the ore until recently when Magnet Cove commenced production from underground operations. Development of the underground workings began in 1946, but no production was realized until April, 1949.

Both companies have used similar methods in stripping the overburden and removing the ore from their respective pits. Stripping and mining are done simultaneously, waste removal being enacted at one place in the mine while ore mining is progressing in an area previously stripped. National Lead contracts a portion of their stripping work, but all of the barite mining is done with company labor and equipment. Magnet Cove Barium, previous to producing underground, had a small portion of both stripping and mining done by contract. The McGeorge Contracting Company does this contract work for both companies. Since the market demand is so great, a long range waste removal program is curtailed in favor of a maximum amount of ore being supplied to the mill each month.

The blast holedrilling is done with small, gasoline powered, auger type wagon drills and with churn drills. Since the mining has not proceeded to great depths, no standard benching has been followed to date. After blasting, the broken ore and waste are

FIGURE 6. Conveyor loading station of National Lead Company, at Magnet Cove, Arkansas.

FIGURE 7. Stripping the shale overburden on National Lead property at Magnet Cove, Arkansas in preparation for the installation of a conveyor.

loaded into trucks by power shovels and hauled from the pits to the crushing and concentrating plant.

A large belt conveyor system for transporting the ore and waste out of the pits has been installed by the National Lead Company. The system was designed to handle 1300 tons of material an hour. From loading points in the pits, the conveyors proceed to a main transfer station which is located just east of the deposit. At the transfer station, the waste is transferred to a conveyor which transports the rock northward and by means of a telescopic type stacking conveyor dumps the waste into a relatively deep, narrow valley. The ore is carried about 100 yards to the south of the main transfer station to the crushing plant. As presently planned, the deepest part of National Lead's operation will be over 600 feet below the elevation of the main transfer point. The system is not working at full capacity as yet and at the time of the latest information the writer has obtained, no ore has been hauled from the pits by means of the conveyor. A large tonnage of waste, however, has been handled by the system and such operation has proved successful. There are many problems to solve concerning the operation of the conveyors, principal of which is discovering the most efficient and economical method of locating the loading stations to follow the stripping and mining operations with a minimum number of moves. At the same time, the trucking distance from the point of operation to the conveyor loading stations must be kept at a near minimum. Another consideration which must be recognized in regard to the moving of the conveyors is that a minimum amount of ore must be tied up under the conveyor. As the operation increases in depth toward the center and western end of the deposit, these problems will become increasingly important and more difficult to solve.

Magnet Cove Barium Corporation began underground development by cutting a slot in the novaculite footwall on the north flank of the deposit and by sinking a shaft when the bottom of the existing pit had been reached with the slot. The shaft was sunk to the point where the ore body began to flatten out near the bottom of the syncline. The inclination of the slot and shaft was nearly 60° from the horizontal. A two compartment shaft was constructed utilizing balanced skip hoisting. Concrete and steel construction was used for the slot, and steel members were employed throughout the shaft and the underground workings. The steel headframe has provisions for handling the bottom dump skips which were installed. The hoist house has the most modern equipment available and is a good example of up-to-date mine plant construction. Drifting was begun from the bottom of the shaft in preparation for a modified block caving mining system. During the time of this development the company continued to produce ore from the open cut operation doing as little stripping as necessary. Since the start of ore production from underground in April, 1949 no definite information has been obtained by the writer, but it is believed that there is no continuation of the open pit mining.

Beneficiation Methods

Concentration of the Magnet Cove barite is far different from the simple washing operations used at other barite properties in Missouri, Georgia, and elsewhere. The ore must be finely ground for

FIGURE 8. View looking northwest along the north flank of the Magnet Cove deposit. Headframe for the shaft of Magnet Cove Barium Corporation is shown in the background.

FIGURE 9. Part of the National Lead Company's mill at Magnet Cove, Arkansas as seen from the tailings pond. Crusher building is to the left of the picture.

liberation of the barite and froth flotation is necessary for good concentration. It is not known how far back commercial flotation of barite was considered, but evidence shows that barite flotation practice pre-dated 1931. Fred D. DeVaney, in a letter dated March 16, 1931 to George C. Branner, State Geologist of Arkansas, concerning an investigation of possible concentrating methods for the Magnet Cove barite by the Bureau of Mines, stated: "Inasmuch as barite is at present being successfully concentrated by a similar flotation process in California, the process may be said to have gone beyond the experimental stage and there is every reason to believe that the ore you sent us can be satisfactorily concentrated by the flotation process." This letter appeared in the Appendix of a report by Parks.[26] The present process used is based on the

(26) B. Parks, op. cit., p. 48.

investigation made by Norman and Lindsey in 1939. This work appeared in the May 1941 issue of Mining Technology. DeVaney (see above) said that the ore must be ground to 150 mesh for successful concentration by flotation while Norman and Lindsey's tests were run after grinding the ore to minus 325 mesh. This latter figure is the mesh size to which the ore is ground by both companies operating at Magnet Cove. Norman and Lindsey[27] further stated:

(27) J. Norman and B. S. Lindsey. Flotation of barite from Magnet Cove, Arkansas. AIME Tech. Pub. 1326, Mining Technology, May 1941. p. 5.

"After liberation of the minerals, satisfactory separation of barite and gangue could be obtained by froth flotation without desliming, with sodium silicate, a fatty acid, and pine oil as reagents, ..." However, this has not been upheld, since in the commercial operations desliming has proven necessary previous to flotation.

Both companies use flotation to recover the barite, but Magnet Cove Barium floats the barite only whereas National Lead operates two circuits; the "high-grade" circuit, in which the gangue, which is primarily silica, is floated and the "low-grade" circuit, in which the barite is floated. Present plans for mill expansion at National Lead include elimination of the high-grade circuit and conversion of all the flotation equipment to the floating of barite. The mills of both companies are similar and since two sources of information concerning the flow sheet at National Lead are readily available,[28] a generalized summary of the latter will be given.

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(28) A. C. Harding. Barite production in the United States. AIME Tech. Pub. 2414, Mining Technology, July 1948. p.4. Also, Mill Flow Sheet 1948, Drawing M-92, courtesy of the Baroid Sales Division, National Lead Company.

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spiral ?

The ore is crushed, screened and classified by a screw classifier with the over flow being sent to a hydroseparator. The screen oversize is in closed circuit with crushing rolls. Sand underflow from the hydroseparator is sent to the grinding circuit. The overflow of minus 200 mesh material goes to a thickener, thence to the flotation circuit. Classifier underflow from the spiral screw classifier mentioned above, is conveyed to a six-compartment 1000 ton mill bin. From here it is sent to a jig feed bin, then to the primary jigs.

NOT TRUE!!

MAGNET COVE BARIUM CORP. DID NO DE-SLIMING DURING PERIOD JUNE 1940 ~~to~~ TO MAY 1950. INSTALLED CENTRIFUGE IN 1950 AS AID TO CUTTING REAGENT COSTS.

The concentrate from these primary jigs is transported to the high grade grinding circuit. Tailings of the primary jigs go to secondary jigs from which the concentrate product flows to the low grade grinding circuit. The tails from the secondary jigs go to a dewaterer from which the minus 60 mesh is sent to the hydroseparator. The plus 60 mesh from the dewaterer is disposed in the tailings pond. Both grinding circuits use conical ball mills in closed circuit with bowl classifiers. Classifiers are set so that the overflow is 95 per cent minus 325 mesh. The overflow is thickened and sent to centrifuges where the slimes are removed and disposed in the tailings pond. The centrifuged products are conditioned and passed to rougher flotation cells followed with a bank of cleaner cells. Amine reagents are used to float the silica in the high-grade circuit. The concentrate (that is, the material not floated) goes to a thickener, is then filtered, dried and sacked. The froth, or gangue, is sent to the low grade circuit. A fatty acid reagent is used to float the barite in this circuit. The material flows through a bank of roughers, then through three banks of cleaner cells. Middling products from the three cleaner operations are combined, sent to a hydroseparator where the sands are recirculated through the entire circuit. The final concentrate is combined with the barite product from the high grade circuit and, therefore, undergoes the same thickening, filtering, drying and sacking treatment given above.

The mill of the National Lead Company is located within 1000 feet of the deposit. Previous to 1948, the finished product was trucked some five miles to the village of Butterfield where it was loaded for shipment on the Chicago, Rock Island and Pacific Railroad. Since the late fall of 1947, however, trucking has been discontinued and the loading of the railroad cars takes place at the mill site where a spur track has been constructed from Butterfield. Magnet Cove Barium Corporation's mill is located in the city of Malvern. The run-of-the-mine ore is transported the 12 miles by a fleet of dump trucks.

In 1944 the capacity of both mills was 7500 tons per month, but recent expansion at National Lead has increased their capacity to over double that figure.[29] Further expansion is being planned

(29) R. B. McElwaine, op. cit., p. 5

by both producers. Benston[30] says that at National Lead the

(30) O. J. Benston, op. cit., p. 27.

"plant capacity is not yet fully established but the current rate (of production) is at about 30 tons of product per hour".

Almost 100 per cent of the production of both plants goes for use in drilling muds, National Lead's product being called "Baroid" and Magnet Cove's being marketed under the name of "Magcobar".

Missouri

Washington County District

Location, Topography, and Climate

The Washington County district normally applies to the barite deposits located in the southeastern quarter of the state, the principal producing areas being in Washington County. Barite occurrences extend into Jefferson, St. Francois, Crawford and

Franklin counties as shown by the Mineral Resources Map of Missouri published in 1944 by the Missouri Geological Survey.

Potosi, the county seat of Washington County, is the largest town in the producing area and is located approximately 70 miles south of St. Louis by way of State Highway 21. Early lead mining activity in the 18th Century caused the settling in this general area of Missouri, the village of Mine au Breton being founded in 1763. The name of this village was later changed to Potosi. There has been little lead mining in Washington County in the last 60 years.

The chief shipping points for barite are Mineral Point and Cadet, located five and ten miles, respectively, from Potosi, and are situated on the main line of the Missouri Pacific Railroad. There is a branch line of this railroad running from Mineral Point to Potosi.

This barite-bearing area is in the Ozark region, the district as a whole being a plateau which is termed the Summit platform by Marbut.[31] The platform lies west of the Avon escarpment and east

(31) C. F. Marbut. Physical features of Missouri. Missouri Geological Survey, Vol. X, 1896. p. 55.

of the Potosi escarpment. The topography within the plateau is gentle and rolling with the elevation varying from around 1000 feet at the southern part to near 800 feet at the northern end. The Potosi escarpment trends northwest-southeast with a maximum elevation of approximately 1250 feet in the south which declines to about 1050 feet at the north. Both the escarpments mentioned above face an eastwardly direction and this gives the area to the west of the Potosi escarpment a higher average elevation than the elevation of the Summit platform.

The principal drainage is by Big River which flows northward along the east side of the district to the Meramec River. Some of the major streams flowing into Big River from the barite area are Mineral Fork, Mill Creek and Calico Creek. Near the northern extremities of the barite field, Little Indian and Indian Creeks flow northward directly to the Meramec River. A low elevation of less than 550 feet is found along Big River north of the junction of Mineral Fork.

The mean annual temperature is near 60° and the rainfall averages about 45 inches. Much of this precipitation occurs in the spring and early summer, although considerable snow falls each winter. The temperature varies greatly, even within the span of 24 hours, and this condition is favorable to extensive weathering of the rock.

General Geology

The stratigraphic sequence of the formations in the Washington County barite district is given as follows:

Ordovician

Roubidoux

Gasconade

Cambrian

Proctor

Eminence

Potosi

Derby-Doerun

Davis

Bonneterre

Lamotte

Shown as a group on the Geological Map of Missouri, the Potosi, Eminence and Proctor have by far a greater area of exposure in the district than any other formation or group of formations. Some geologists consider the Proctor as a part of the Eminence. Of these three, the Eminence outcrops most extensively. The Gasconade is exposed in a few places, principally along the top of some of the higher ridges in the area. Several miles south of Potosi, the Roubidoux outcrops in a limited degree, but this is out of the region of present barite production. The group consisting of the Derby-Doerun, Davis and Bonneterre is exposed in the valleys of some of the major streams.

Lithologically, the Cambrian formations consist in large part of calcareous beds, principally dolomite and dolomitic limestone. The Lamotte, however, contains beds of quartzitic sandstone, with only the transition phase between this formation and the Bonneterre showing calcareous facies. The Davis is normally termed a shale formation because it contains a greater number of shale beds than any of the other formations, although much of the rock is a dolomite. The remainder of the formations consist primarily of massive dolomite, both crystalline and earthy in texture, ranging from light gray to buff color with some of the horizons containing considerable chert.

Of the Ordovician sediments occurring in the area, the Gasconade is principally a dolomite having a light gray color and containing much chert. The lower part of the Gasconade is sometimes distinguished as the Van Buren. The Roubidoux contains a variety of rock in its exposure over a large area in Missouri, but in the Potosi quadrangle it is predominately a sandstone. Its color is a light gray and where weathered turns to a reddish brown.

A greater part of this preceding discussion concerning the lithology of the formations has been taken from the book by Dake[32] on the geology of the Potosi and Edgehill Quadrangles.

(32) C. L. Dake. The geology of the Potosi and Edgehill quadrangles. Missouri Bureau of Geology and Mines, Vol. XXIII, 2d Series, 1930. pp. 44-168.

The district lies northwest and west of the St. Francois Mountains which are the structural center of the Ozark dome, thus making the regional dip toward the north and west. Except in a few localities, this dip is less than ten feet per mile.

The other structures are simple and there are no areas of extensive folding or faulting. However, all the formations show minor folds and warps, but these are generally considered to be due to consolidation and compaction of the sediments. In regard to major folds, Tarr[33] has the following to say: "There is really but one important fold in the area and that is slight in

(33) W. A. Tarr. The barite deposits of Missouri. University of Missouri Studies, Science Series, Vol. III, No. 1, 1918. p. 41.

comparison to the folds of many regions. This is an anticline which extends from the Richwoods region (in the northwest corner of the barite district) to the southeastern part of the area near Kingston, where it apparently turns eastward and follows, rudely, the course of Big River."

In all of the references consulted, the writers state that they have observed but few faults in the district. However, some who support the igneous theory in explaining the primary origin of the barite say that in all probability many faults once existed and have either been eroded or hidden by other sediments. In any case, fault structures are certainly not now prominent in the region.

Geology of the Deposits

There are three modes of occurrence of barite in the Washington County district, although only one is of economic significance. The types or forms of the barite found in the region will be considered under "Description of the Ore". The principal production is from the Potosi with no barite occurring in older formations although some deposits are noted in the Eminence, just above the Potosi. Even though the Gasconade contains no barite in this area, it is the major producing formation of the Central district, which will be discussed later.

Minor quantities of barite occur as veins in both the Eminence and Potosi sediments. Little if any production comes from the veins, as they are normally thin, varying in thickness from an inch to one foot, and irregular along their outcrop. The exposures are few in number, usually being noted along the bottoms of creeks and streams or on the slopes of steep ridges where the usually thick mantle rock has been eroded. Tarr [34] describes these veins as

(34) Ibid, p. 64.

fissure fillings, the barite having been introduced by ascending igneous solutions. He says that although seldom exposed, they are in abundance in the unweathered portions of the dolomite under the residual mantle. "In only a few instances were the larger veins seen, and then they were in areas of residual barite. The smaller veins are very numerous and are in the same areas as the large ones, although small sporadic veins may be seen almost anywhere in the upper part of the Potosi." This would seem to indicate that the residual barite is a direct result of the weathering of the barite lodes, the dolomite having been dissolved and carried away while the barite and chert remained. Dake,[35] on the other hand, believes that the veins are not widely distributed, and are not the source of the residual barite because "the observed distribution and abundance of veinlets is inadequate to account for the present quantities of residual barite occurring in the clays."

(35) C. L. Dake, op. cit., p. 200.

A second mode of occurrence is that of the barite found in solution cavities or caves in the bedrock. The barite is usually in the form of large boulders, many weighing as much as several hundred pounds. Some of these cave deposits have been mined, but the duration of production is normally short and no appreciable quantity of barite has been exploited from such deposits as a group. These caves are thought by Dake [36] to be "typical modern

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[36] Ibid, p. 201.

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caves, in which cases they are doubtless related to the present erosion cycle and the barite secondary."

The third mode of occurrence, and the most important economically, is the so-called "residual barite", which is found extensively over the Washington County district. Such deposits are much easier to mine and a greater concentration of the barite is present than in the vein and cave deposits. The residual barite is found scattered through a red clay mantle which covers the entire area.

The mantle is a product of the weathering of the Eminence and Potosi formations, the red color being due to the iron oxide present. Remarkable plasticity is characteristic of this clay and it is highly impervious. In depth, this mantle seldom exceeds 20 feet and almost never is greater than 30 feet. Although the barite is distributed throughout the clay blanket, a greater concentration is noted just above the dolomite bedrock. Some form of silica is invariably found with the barite, either as chert, chalcedony or quartz. A variety of silica commonly occurring with the barite has been termed "druse", which is banded chalcedony coated with quartz.

Both the origin of the residual barite and the method by which it arrived at its present distribution in the mantle are still debatable. Many who agree on the origin of the residual barite, find disagreement concerning the origin of the original barite from whence they believe the residual ore was derived.

Many investigators consider the residual barite as resulting from the weathering of the dolomitic bedrock containing the barite veins and barite filled solution cavities. They maintain that the carbonates were dissolved and the insoluble material remained or was transported only a short distance mechanically. This residuum is the red clay as presently found containing insoluble barite and druse or other forms of silica. In attempting to establish the origin of the barite thus contained in bedrock, two theories have been expounded. One theory accredits the barite deposition to precipitation from cold, descending meteoric waters, which had received the barite from the surrounding rocks, in fissures and other openings. The second theory proposes that the barite has been deposited in the fissures and cavities from ascending hot solutions of igneous origin. Those who support the former point out the fact that apparently no barite occurs in formations below the Potosi, which would not be the condition if rising solutions were the carrier of the barite. In addition they show that there is no effect of heated solutions in the vein deposits, and furthermore, no igneous rock is known to exist in the area of barite deposition. Evidence given in favor of the igneous theory includes: (1) the solubility of barium salts is not conclusive to their being carried in solution by meteoric waters; (2) the galena and sphalerite found associated with the barite are thought to be igneous in origin because of their mineralogical character; and, (3) little barium is known to exist in sedimentary rocks, calcareous rocks in particular, and the greater abundance of barium occurring in igneous rock.

Dake (37) proposed another theory of the barite origin. He

(37) Ibid, pp. 204-208.

considers it plausible that the barite and the druse were deposited in colloidal form simultaneously with the deposition of the dolomite by sea water. He postulates that the residual barite, as it now exists associated with large accumulations of druse, quartz and chalcedony, is the result of the reprecipitation of these minerals from circulating meteoric waters which had previously dissolved them from the dolomite. The precipitation probably occurred within a short time after the colloidal particles went into solution. The veins, as a source of the present residual barite, are discounted by Dake, for he believes that their abundance and distribution are not adequate for the accumulation of such widespread barite deposits. Those who adhere to the theory that the veins were directly responsible for the accumulations of residual barite state that although a great number of veins have not been noted in the district, there are many which are covered by the mantle. In refuting this part of the "vein-theory" of origin, Dake readily admits that the statement can't be substantiated nor can it be conclusively denied, but he asks why numerous veins are thought to be concealed within the district when in the exposed areas there are so few veins found. In further attempts to discredit the igneous theory in particular, he presents several points for consideration. His first argument deals with the Davis formation which underlies the entire area. Although predominately dolomite, the Davis consists of many impervious shale members. With little faulting in the area, Dake thinks it improbable for rising solutions to reach the overlying Potosi and Eminence. He shows that the druse which is associated with the barite is present in the dolomites (Potosi and Eminence) in minute quantities and this druse certainly could not have been introduced by igneous solutions. The argument put forth in favor of the igneous theory concerning the solubility of barite is objected to by Dake because barite is not insoluble, but only low in this characteristic, and that geologic time conquers such chemical principles of insolubility, as is the case with the silica leached from Lake Superior iron ores.

In summary, it might be stated that the origin of the Washington County barite is definitely not conclusively established and that until a closely detailed study and investigation is made in the district, the origin will remain a controversial issue. In regard to modes of occurrence, only one is of economical importance; the residual deposits which occur throughout the red clay mantle covering the area. It is doubtful to the writer if the veins and solution cavities containing barite will ever be of economic significance.

Description of the Ore

The most familiar type of "tiff", as the Missouri barite is called, is the crested type. Such barite is actually an aggregate of curved, tabular, white barite crystals which are crested in structure. Silica is always found with the barite as druse, chalcedony, chert or quartz. Other minerals in the form of sulfides, oxides and carbonates have been described as occurring with the barite, but they are in minor quantities. A reddish-brown stain of iron oxide often coats the crested barite. Some limonite is found accompanying the barite and not infrequently it takes a shape pseudomorphic after marcasite or pyrite.

Other forms of barite are mined in the area. Included is a type of adulterated material of cone shape which is usually covered with divergent crystals of more pure barite, resembling the crested type mentioned above. The cone-shaped masses are very large, often weighing several hundred pounds. Tarr [38] reported two other forms

[38] W. A. Tarr, op. cit., p. 61.

of barite; namely, "chalk tiff" which is a finely granular, porous variety of barite, and "ball-tiff", a finely crystalline, concretionary barite in which the tabular faces are curved.

Mining Methods

All of the barite produced in the district previous to about 1925, and a greater percentage of the production from this date to 1939, was mined by primitive hand methods. Owners of barite-bearing land leased their property to individual miners. The miner and his family lived on the property and all the members of the family usually participated in the exploiting of the barite. These people were commonly known as "tiff diggers".

Small shafts about 3 to 5 feet in diameter were sunk and the mantle containing barite was "shovel hoisted". If the upper portions of the shaft needed cribbing its shape was normally square, otherwise the shaft was circular in plan. The depth of mining was from four to twenty feet, although a few of the workings reached a depth of thirty feet. Many miners would install a crude hand windlass when the shaft became too deep to shovel out the excavated material. Some, however, merely abandoned the shaft and began other workings nearby. The miner excavated eight to ten feet horizontally when the shaft was bottomed, thus obtaining a diggings which closely resembled the shape of an inverted mushroom. Such practice often led to intersection with previous workings from other shafts and gave the miner a large area in which to mine. The extent of the "belling out" was governed by how well the ground would stand without support. Natural ventilation was used except in some cases where other workings were encountered, at which time a fire built at the bottom of one shaft would induce ventilation.

The ore the miner dug in this way was usually hand sorted and sold to the nearest washing plant. A chisel pointed ax or hatchet was used to knock off much of the red clay and chert or druse which was attached to the lumps of barite. A royalty was paid to the landowner from whose property the miner obtained his barite after he had received payment from the washer operator for the ore.

In 1939 the Federal courts affirmed a decision of the National Labor Relations Board that the "tiff diggers" of Washington County were employers of the landowners. The landowners, fearful that this action would force them to pay the miners the minimum wage which would greatly reduce the profit, ceased letting the miners dig on their properties. This condition, together with the fact that barite had grown in economic importance, thus creating a desire for greater production, led to the introduction of mechanised equipment on a relatively large scale. A limited tonnage of barite had been mined with power shovels previous to 1940, but it was in that year that production by hand mining methods was reduced to only a small percentage of the total.

Inasmuch as the overburden is usually shallow or often absent entirely, the power shovels load all the material mined into trucks for transport to the washers. There are, however, a few places where stripping is possible and it is sometimes economical for a stripping program to be pursued. The surface mines from which the barite is obtained are locally termed "diggings", and the barite ore mined in the "diggings" usually occurs as "leads". These "leads" are followed until they are exhausted.

Trucks haul the ore to the washers, which are normally within two miles of the "digging" being worked. These washers are of a temporary construction because they must be moved frequently to remain within an economic hauling distance of the "diggings".

Beneficiation Methods

The barite is concentrated from the crude ore at small concentrating plants termed washers. All the washers operating in the district are similar in the means by which they mill the ore. Trucks hauling the ore from the diggings dump their load into hoppers at the washer. A strong jet of water normally is used to wash the ore into the primary crusher or breaker, and also serves the purpose of removing a part of the red clay clinging to the rock. Several different types of primary breakers are employed, the most common one being a rotating grizzly or "squirrel cage" made of rails with a spacing of four to five inches. As the grizzly rotates, the softer barite breaks up and falls through the space between the rails, while the harder quartz remains within the grizzly and is subsequently rejected to waste dumps. Thus, the grizzly works as both a primary breaker and a rough concentrator. Removal of the red clay associated with the barite is next accomplished. This clay elimination is effected with the use of double log washers, from which the overflow travels to the tailings or mud ponds. The washed product from the log washers is choke fed to a trommel screen. Active grinding action is maintained by providing the trommel with a small diameter discharge which keeps the trommel nearly half full of material.[39] Barite, being considerably

(39) Evan Just, Barite production upheld by improved equipment. Engineering and Mining Journal, Vol. 149, No. 1, January 1948. p. 73.

harder and heavier than the associated quartz, works its way by centrifuging to the outside of the rotating trommel and because of its relative softness is broken by the grinding action and passes through the screen openings. Meanwhile, the quartz moves inward as a result of the barite movement and is discharged through the outlet at the end of the trommel. This discharge is rejected as waste.

Having passed through the screen openings, the barite is conveyed to a storage bin from which the jig feed is drawn. In like manner to the trommel, the jigs are crowded with feed. From the

FIGURE 10. Barite ore of Washington County, Missouri showing the contrast of the red clay and the white "tiff".

FIGURE 11. Mining barite in Washington County, Missouri. Note the shallow depth of the operation.

FIGURE 12. Richwoods washer of the DeSoto Mining Company, Washington County, Missouri

jigs, the concentrate product flows into a rake classifier. The overflow of the jigs and the classifier go to the tailings pond while the classifier underflow is stored in the concentrate bin.

The principal difficulty encountered in concentration of the ore is that caused by the limonite. Weigel [40] states: "Where the barite is coated with a hard film or layer of limonite, matters are complicated somewhat, as even if the limonite is crushed fine enough to free it from the barite, its density (3.8) is so near that of barite (4.3 to 4.6) that separation by gravity methods is difficult, especially as the barite tends to break into tabular and the limonite into granular form." For this reason, a considerable quantity of barite concentrate of the Washington County district contains substantial amounts of iron oxide. This is not harmful for the barite utilized as a weighting material in oil well drilling muds, but the iron content must be lowered if the product is to be used in lithopone or barium chemical production. Such iron reduction is accomplished at several washers by magnetic separation processes.

Two representative washer flow sheets are shown in Figure 13. These were taken from the article by Evan Just. [41] He states that there are more than 20 washers now operating in the Washington County district. There are several grinding plants in operation within the district where the washer concentrate is wet ground to any desired

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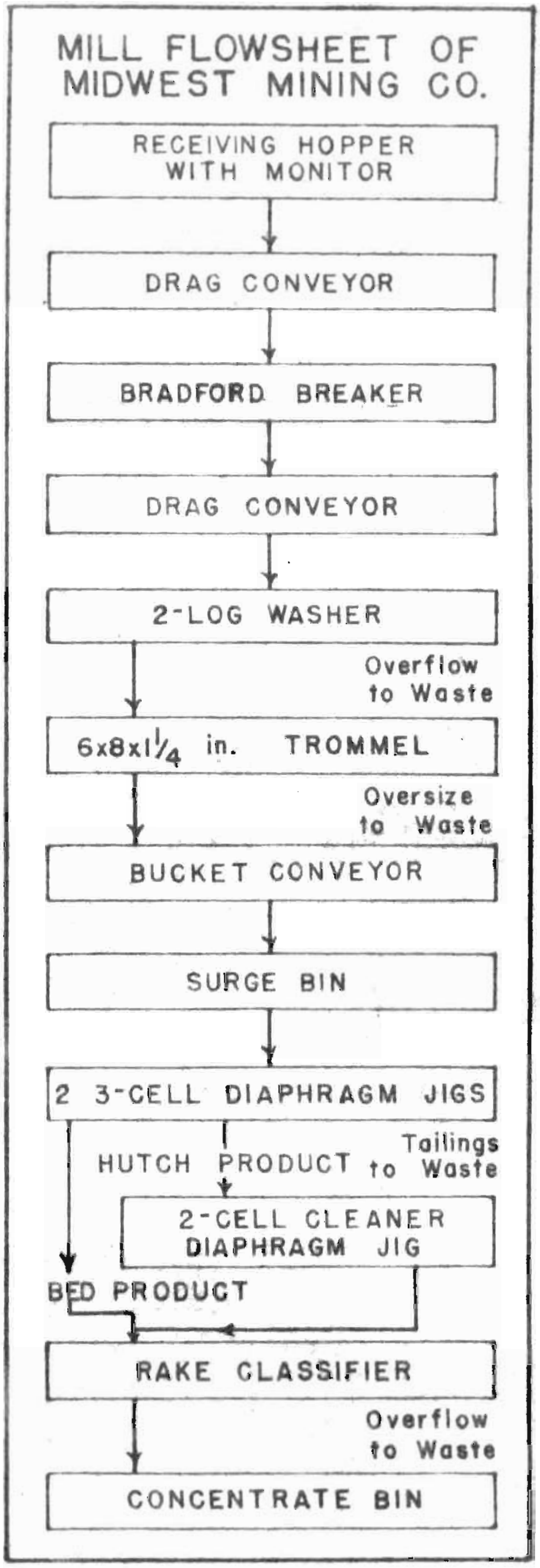
[40] W. M. Weigel, The barite industry in Missouri. AIME Transactions, 1929. p. 273.

[41] Evan Just, op. cit., p. 72, 73.



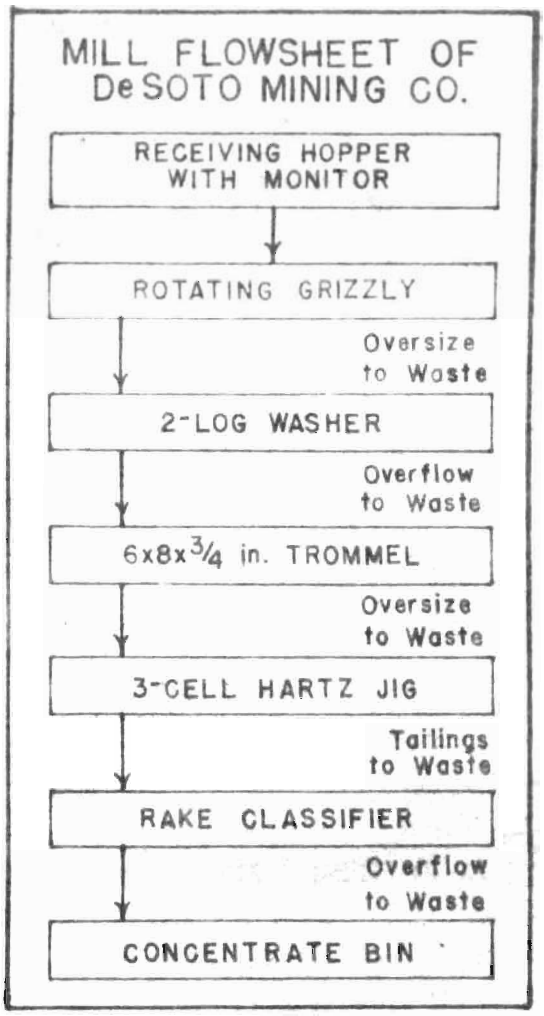


FIGURE 13. Mill flowsheets of two Washington County barite producers (after Just)

mesh. The Baroid Sales Division of the National Lead Company formerly operated a black ash plant in conjunction with their grinding plant, but production was discontinued several years ago.

The district has been known for the high purity of the barite which is produced and although considerable tonnage now goes into drilling mud, a good portion of the supply is still employed for lithopone and barium chemical production.

Many improvements in the beneficiation of Washington County barite will undoubtedly be initiated in future years. Much fine barite is lost in the washing processes and the tailing dumps reportedly run high in barite content. The Bureau of Mines has investigated the use of the Humphrey spiral in reclaiming these tailings. Further investigation is being done with other mineral dressing equipment both at the Bureau and at Missouri School of Mines and Metallurgy.

Central District

Location and Topography

The Central district includes parts of Benton, Cole, Camden, Cooper, Moniteau, Morgan, Miller and Pettis counties. Although the barite deposits cover a much larger area in this district than in the Washington County region, they are not continuous and only a few are being mined at the present time. The tonnage from the district is less than five per cent of Missouri's total, although in past years as much as 15 or 20 per cent of Missouri's annual barite production came from the Central district.

As the name implies, this region embraces counties in the central part of the State. Jefferson City, the capital city of Missouri, is in Cole County a few miles east of the barite area. Sedalia, county seat of Pettis County, lies on the western border of the district. The Missouri River borders the district on the north and Lake of the Ozarks could be considered the southern and western boundary inasmuch as little barite is found south or west of the lake.

The district lies on the northwestern slope of the Ozark Uplift. The north and western portions of the area are within the Springfield Structural Plain while the southern and eastern part is on the Salem Platform.(42) "The higher portions of the region have a relatively slight relief and are splendid agricultural lands, but the portions along the Missouri and the Osage Rivers and their larger tributaries are very rough, and not well adapted to agriculture, although the large part of the acreage is so used."(43) The principal drainage is by the Osage River.

(42) C. F. Marbut, op. cit., Plate II.

(43) W. A. Tarr, op. cit., p. 50.

Geology

The same geologic column given for Washington County is applicable to the Central district. There are, however, several additions. Within the region, the Jefferson City dolomite covers an extensive area. This formation has been classified as Upper Ordivician and occurs stratigraphically just above the Roubidoux. Some Devonian, Mississippian and Pennsylvanian formations are noted but they cover only a small section in the northern part of the district.

The Jefferson City dolomite is a cherty, gray dolomite with interbedded dolomite as an earthy type termed "cotton rock". It covers much of the area in the north sometimes attaining a thickness of nearly 300 feet. In the southern part of the area, the Roubidoux and Gasconade are exposed extensively.

Mather (44) divides the deposits into the following six transitional classes or types: (1) fissure; (2) breccia; (3) circle; (4) solution channel; (5) replacement; and (6) residual deposits. Of these, only the circle and residual types are of economic importance at the present time. He describes the circle structures as having developed from solution channels in the dolomite by the caving of the surrounding rock and subsequent mineralization after the caving had ceased. Although types 1, 2, and 4 contain considerable galena and sphalerite, only a small amount is associated with the barite in the circle deposits. The circle deposits are found in the Gasconade, Roubidoux and Jefferson City formations. The residual deposits are of the same appearance as the residual type occurring in Washington County. They are located in the weathered portions of the Gasconade and Jefferson City and the barite is distributed in a red clay. There is no druse as is the case in Washington County, but considerable chert is present.

(44) W. B. Mather, Barite deposits of central Missouri. AIME Technical Publication 2246, Mining Technology, September 1947. p. 4.

The forms of barite found are much the same as those occurring in Washington County. In regard to origin of the barite, the same controversy exists. There is considerably more galena and sphalerite with the deposits in the Central district than in the Washington County area and such association is used as support to the igneous theory.

Mining and Preparation

The mining of the deposits is on a small scale as the deposits are small and scattered throughout the area. Weigel,[45] in discussing the hand mining methods formerly used, points out that because the slopes are steeper in the Central district than in Washington County, the mines were opened as drifts into the hillside and vertical faces were developed and worked with picks. Mining today is done principally by open-pit methods.

(45) W. M. Weigel, op. cit., p. 269.

Washers used in the Central district are small and portable. The concentrating processes consist of merely crushing and jigging the ore in the case of the circle deposits, but because of the high grade of the deposits, 95 to 98 per cent barite concentrate is produced. For the milling of the residual ore, log washers are used previous to jigging as is the case in Washington County.

Mather [46] states: "At the present time (1946), there are seven properties being developed and mined, producing less than

(46) W. B. Mather, op. cit., p. 2.

10,000 short tons of high-grade concentrates per year." This production figure has been reduced considerably in the past two years.

Georgia

Location, Physiography and Topography

Barite has been mined intermittently in several counties of northwestern Georgia since 1906. Scattered deposits are known to exist in a belt from the Alabama border in Polk County, northeastward to Murray County on the Tennessee border. Other counties included in this zone are Floyd, Bartow, Cherokee, Gordon and Whitfield. All of the barite mined in the state at the present time comes from the Cartersville district in Bartow County; in fact, a great percentage of Georgia's barite production has originated from the Cartersville area.

Cartersville, the county seat of Bartow County, is situated in the southeastern part of that county, and is some 40 miles northwest of Atlanta. The mining district which has its name derived from the city, begins southeast of Cartersville and extends approximately 18 miles northward. Seven miles is the greatest width of the district, this being near the middle of the barite-bearing tract about five miles north of Cartersville. The principal barite deposits are located in the southern part of the district. (47)

(47) J.P.D. Hull, Report on the barytes deposits of Georgia, Geological Survey of Georgia, Bulletin No. 36, 1920. p. 19.

The district lies in the eastern part of the Appalachian Valley division, which is bordered by the Cumberland Plateau on the west and by the Piedmont Plateau and the Appalachian Mountains on the east, just west of the Cartersville fault. The topography within the Appalachian Valley is gentle, the floor of the Valley being composed in the most part of rolling hills which have a northward trend. Rugged ridges rise to elevations of 1500 feet just east of the Cartersville fault escarpment, but the elevations of the hills west of the fault and within the producing area average between 900 and 1000 feet.

The principal stream in the area is the Etowah River which flows through steep valleys as it enters the barite region from the Piedmont Plateau. It travels westward across the Cartersville district through flat lying, river bottom land, south of Cartersville. The elevation of the river is about 700 feet above sea level. Other streams of importance are the Nancy and Pettit creeks in the western part of the region.

General Geology

There are two formations involved in ore deposition in the Cartersville district, the Weisner and the Shady, both of which are of lower Cambrian age. Small areas of the Conasauga formation, also of Cambrian age, are exposed in the area, but no barite is reported within these beds. Above the Conasauga stratigraphically is the Knox dolomite, the lower part being of Cambrian age and the upper part of Ordovician age, but this formation is not noted in the Cartersville district, although some barite has been obtained from it in the northern part of the state near Elton in Murray County.

The Weisner formation, which is the lowermost Cambrian formation found in the Cartersville district, is of unknown thickness and "is made up of sericite and muscovite schists interbedded with quartzites." (48) The Shady formation, previously termed the Beaver, con-

(48) T. L. Kesler, Structure and ore deposition at Cartersville, Georgia. AIME Technical Publication 1226, Mining Technology, September 1940. p. 2.

tains the principal barite deposits in the region. Much of the Cartersville area is overlain by the Shady and its weathered products. It consists of "series of crystalline limestones, for the most part dolomitic, interbedded with and grading into sericite and muscovite schists whose carbonate content have wide and erratic range." (49)

(49) Ibid, p. 2

The structures present in the area are complex and often difficult to correctly identify. Such complexities were caused by intense folding and faulting with accompanying metamorphism as a result of a tremendous thrust from the southwest. Many tear faults are noted because the thrust became too great at places for further folding. These folds and fault structures are more intense in the southeast part of the area. Metamorphism of the Shady and Weisner formation has been expressed in the recrystallization of much of the rock. Watson and Grasty (50) state that the crushing and brecciation has

(50) T. L. Watson and J. S. Grasty, Barite in the appalachian states, AIME Transactions, Vol. 51, 1915. p. 524.

been so intense that the original bedding of the quartzite is often entirely obscured.

The dolomitic limestones of the Shady have been removed completely from many of the anticlinal folds, leaving the resistant quartzite of the Weisner exposed as the top of the ridges. This situation is somewhat similar to the novaculite ridges of the Zigzag Mountains in Arkansas. The area has another similarity to a previously discussed barite area in that the Shady, where it is not entirely absent, has been weathered considerably producing a deep mantle of red clay much the same as exists in Washington County, Missouri.

In addition to the barite, important commercial occurrences of bog iron ores, manganese oxide ores, sienna, and magnesian limestone have been mined in the region. Minor quantities of brick and tile clays, slate, gold, bauxite and graphitic schist have been produced. Principal activity, however, has been with the deposits of barite and magnesian limestone in recent years.

Geology of the Deposits

In general, there are two modes of occurrence of barite in the Cartersville district: (1) The vein deposits in unweathered portions of the Shady dolomite; and (2) residual barite occurring in the weathered portions of the Shady. Hull,[51] however, makes a more

(51) J.P.D. Hull. op. cit., pp. 12-16.

detailed classification of the deposit types as follows: (1) veins, (2) replacement, (3) breccia, (4) residual, (5) colluvial, and (6) alluvial. Other writers have included the first three as vein type deposits and the last three as residual type. Grouping the residual, coluvial and alluvial barite under a single heading or type seems logical to the writer inasmuch as none of the three occur alone, but are always mixed in any one deposit. All the information at hand certainly indicated that any movement of the barite, whether resulting by stream washing or by mechanical means of hillside creep or gravity fall, has been of a small distance from its place of origin.

In like manner to the Missouri deposits, the only type of economic worth is the accumulations of barite in the residual mantle. The concentrations are normally found on the sides of ridges or hills from which the Shady has been removed, the weathered material having been washed down-slope where it has combined with the residual clays forming the deep mantle rock. In most cases, limonite or sienna is found with the barite on these slopes, and in many places, manganese oxide is also found. The so-called "sand wall" of the deposits is the Weisner quartzite which dips beneath the residual blanket in which the ores are contained.

The same basic theories of origin suggested for the Missouri barite have been propounded for the Georgia deposits. However, the igneous theory is better substantiated in Georgia because of the many faults which are present and because of the other minerals associated with the barite. Kesler [52] believes that the minerals were deposited from ascending hydrothermal solutions in the lower part of the Shady near the contact of this formation with the Weisner. He states that the emergence of the solutions from relatively inert quartzites to the greatly susceptible overlying dolomites gave the normal result of mineral deposition. It is pointed out by Kesler

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[52] T. L. Kesler, op. cit., pp. 2-4.

that if the ore minerals had been deposited simultaneously with the sediments and, therefore, dispersed throughout these sediments, the deposits resulting from weathering would be more or less equally distributed over the entire district. This, however, is not the situation. The ores are strictly localized and, according to Kesley, "occur under widely divergent conditions of drainage." He, therefore, discounts the theory that the ores in the region have been concentrated by downward circulating meteoric waters during normal weathering from disseminations of the ore minerals in the Shady dolomite. It is his belief that erosion of the land surface lowered the zone of weathering to the hydrothermal deposits existing in the fault structures of the lower Shady, and the ores occurring within the mantle are the weathered products of the original source minerals within these veins. Barite, however, was not altered by the weathering process, but merely left as a residuum.

Hull [53] considers the origin of the barite in the following

[53] J.P.D. Hull, op. cit. p. 16.

way: Barium, derived from the feldspars and micas of crystalline rocks, was removed by meteoric and thermal waters which circulated downward. He postulates that these waters then ascended from uncertain depths to the calcareous rocks where favorable precipitating reactions caused the deposition of barium sulfate or barite.

The barite occurs as both crystalline and granular types. The crystalline variety appears as convergent crystals with a crested structure. Both fine and coarse textured crystalline barite is found, usually white or with a bluish color. The granular type is dull white with occasional coloration resulting from iron or manganese present. Both of these types occur in angular fragments, with sizes ranging from that of a grain to large boulders weighing as much as 25 pounds.

Mining Methods

The mining of barite in the Cartersville district has been described in an article by David P. Hale in the Mining Technology of the AIME in September 1938. Much of the following information has been taken from Hale's paper.

At the beginning of barite mining in Georgia, hand methods of extracting the ore were employed. The ore lumps were stripped of the sticky clay and particles of quartz by a hand pick and the ore thus cleaned was shipped. Within a short time it became apparent that large-scale operations were applicable to the mining of the deposits, and steam shovels were put in use. Until the late 1930's, no stripping was done, but since that time a program of overburden removal has been practiced. The overburden depth is normally between 12 and 15 feet. The stripping operation is kept in advance of the ore mining by a horizontal distance of approximately 20 feet. Benches are carried at heights of about 11 feet.[54]

[54] G. L. Harness and F. N. Barsigian, op. cit., p. 15.

Steam shovels have been replaced by gasoline or diesel powered shovels. The latter are not as rugged and probably lack the digging power of the former, but their efficiency and mobility certainly justify their use. Ore and waste are loaded into gasoline or diesel trucks by the shovel. The ore is hauled to a washer which is situated at a distance seldom exceeding one mile from the mining operation. Most of the trucks employed in the transportation of the ore are $1\frac{1}{2}$ or 2 ton size and are capable of transporting about 3 cubic yards. One producer, however, has found it advantageous to use trucks of 5 cubic yard capacity.

In recent years some operators have used hydraulic methods to mine primary ore and to obtain tailings from mud or tailings ponds for retreatment. Hale (55) gives the following description of hydraulic mining as used to extract primary barite in the Cartersville area.

"In the spring of 1938, one company encountered difficulty with large limestone pinnacles, and hydraulic mining has been fairly successful in that mine. Two 2-in. nozzles are used, one for mining in the cut wall and one to wash the ore to the sump. The sump is covered with a steel plate with 3-in. round holes. Oversize ore is thrown out to one side, as is the large rock encountered, and both are moved at night by truck and a gasoline shovel. The minus 3-in. material goes to a 6-in. centrifugal pump, which sends the ore 300 ft. to a booster pump, also a 6-in. centrifugal. The entire line is 3340 ft. long, the first 2700 ft. being 8-in. pipe and the remainder 10-in. Each pump is driven by a direct-connected 100-hp. motor. The wear on the lower side of the pipe line and in the pump shells, due to the great specific gravity of barite (4.5) have been the greatest difficulties encountered thus far."

Beneficiation Methods

Until the year 1931, the beneficiation of Georgia barite followed much the same pattern as the concentrating procedures used in Missouri. (See pages 54 to 59). In that year, however, one producer installed a Dorr bowl classifier for handling the overflow from the

(55) David P. Hale, Modern mining and beneficiation of barite at Cartersville, Georgia, AIME Technical Publication No. 973, Mining Technology, September 1938. pp. 3-4.

log washers which was formerly lost to the mud ponds. It was soon noted that this was a big improvement in recovery inasmuch as the classifier sands ran as high as 13 per cent in barium sulfate content. At the same time, experimental tables were employed to recover the fine Hutch product from the jigs. After finding that such equipment was successful, they were applied in the circuit for not only the jig fines but also the classifier sands. Operators in the district have made radical changes in their flow sheets to include the use of tables and classifiers which have proved to be economical additions. The installation of fines recovery equipment resulted in provisions for finer crushing and grinding in order to obtain better liberation of the minerals in the ore. Figure 14 is taken from Hale's article (footnote 55, p. 6.) and shows the flow sheet of the producer who first installed a concentrating table as it existed in 1938. Indications are that there has been little change since that year. Harness and Barsigian [56] state that one Georgia producer has installed flo-

[56] C. L. Harness and F. M. Barsigian, op. cit., p. 16.

tation cells to recover the barite from fine material.

Magnetic separation is used for separating the iron oxide from the barite because such parting is difficult by gravity methods. A typical magnetic separation plant has a feed containing 1 to 6 per cent iron. The concentrate averages 0.7 per cent iron and 98 per cent barium sulfate after magnetic separation processes have been applied and the tailings from such an operation contain about 45 per cent iron and 25 per cent barium sulfate.

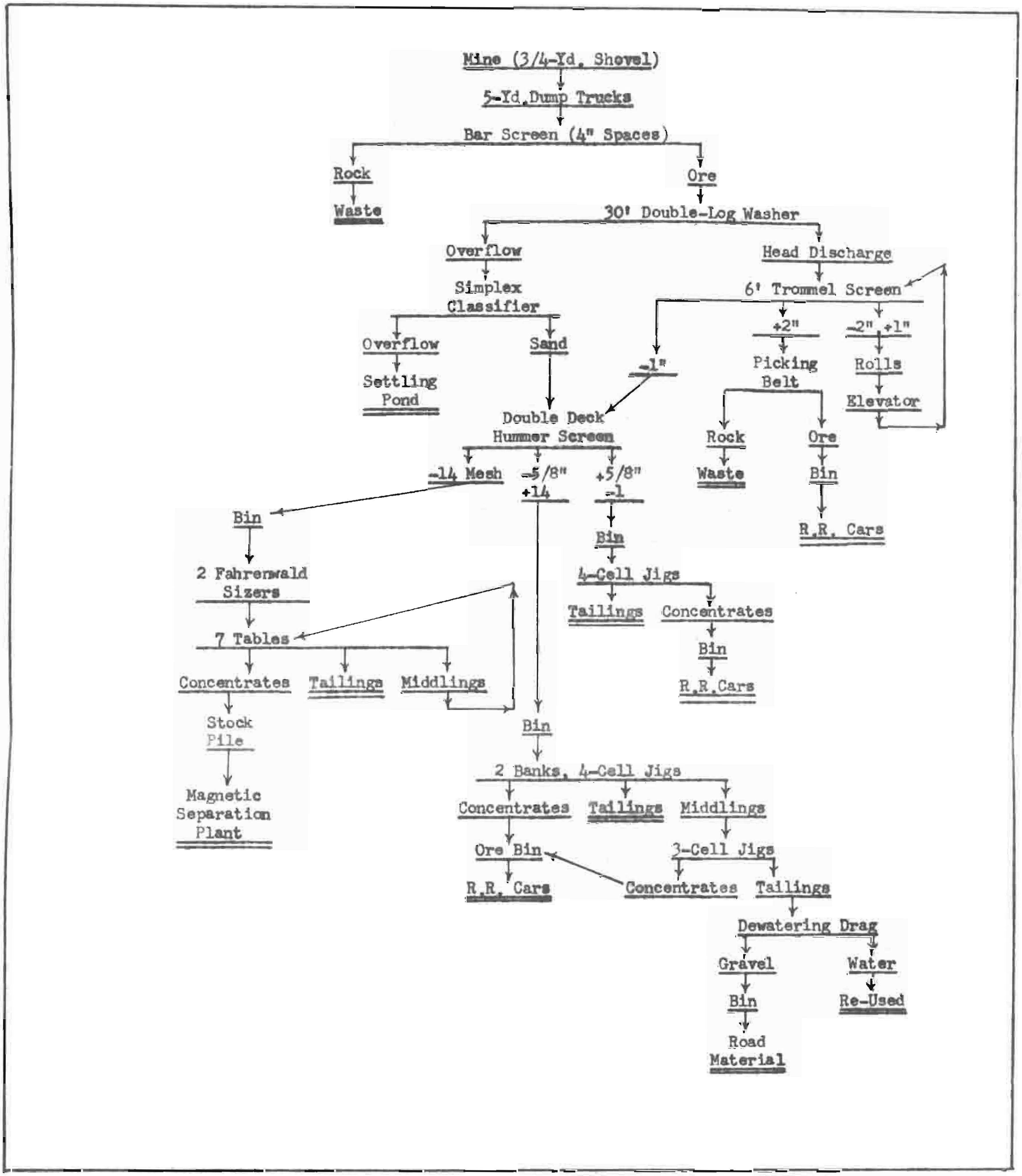

FIGURE 14. Mill Flowsheet of a Georgia Barite Producer

(After Hale)

The last figures available show that most of the barite produced was utilized in the manufacture of lithopone with considerable tonnage going to glass and barium chemical manufacturers. An increasing amount of Georgia barite has been employed as a weighting material in drilling muds, however, since the patent for such utilization expired in 1942.

Other States

Tennessee

Barite occurs in Tennessee in several localities, as follows:

1. Eastern Tennessee
    a. Sweetwater district
    b. Upper east Tennessee district
2. Middle Tennessee

Of these, the Sweetwater district is by far the most important commercially, although some production was reported from Cocke County in upper east Tennessee in 1944. There have been attempts to mine barite from the veins containing barite, fluorite, galena and sphalerite in middle Tennessee but from the references consulted such activity has met with little or no success. Tennessee has, at different times in the past years, ranked second (after Missouri) and third (after Georgia) in barite output. In 1946, Tennessee was the fourth greatest producing state in the United States. (See page 19).

The town of Sweetwater is in southeastern Tennessee, situated about 40 miles southwest of Knoxville and 65 miles northeast of Chattanooga. It is the center of the Sweetwater barite district. The area is in the Appalachian Valley and the topography is of the ridge and valley type much the same as is represented in the Cartersville district of Georgia.

Barite deposits occur primarily in the Knox formation of Cambro-Ordovician age. The Knox is a massively bedded dolomitic limestone containing in places a large amount of chert, locally called "flint". (57) The beds within the Knox which contain much chert stand

(57) C. H. Gordon. Barite deposits of the Sweetwater district, east Tennessee, Tennessee Geological Survey, Vol. VIII, No. 1. January 1918. p. 53.

in more or less prominant ridges because they have a greater resistance to weathering than the massive dolomites. The sedimentary rocks within the region have undergone much stress and the resulting strain has been expressed as highly complicated folds and faults. Many of the folds are overturned which gives rise to the tear faults present. Seven great faults occur within the region in addition to the many minor breaks and slips. (58)

(58) Ibid, p. 54.

The modes of barite occurrence are the same as in Missouri and Georgia. There are veins in the shattered zones of the dolomite and also lumps or masses of barite in the residual clays which have resulted from the weathering of the Knox dolomite. Only the latter is of economic importance. Three veins or belts are noted in the area; the Howard, Garrison and Culveyhouse. They may, however, all be the same merely repeated by faulting. (59) These belts or zones are par-

(59) G. I. Whitlatch. Barite, Tennessee Department of Conservation, Division of Geology, Markets Circular No. 7. April 1938, p. 11.

allel, strike northeast-southwest, and are normally 100 to 300 feet wide and 60 to 80 feet deep. The commercial deposits of residual barite occur only in places along these belts even though some lumps of barite are found in the mantle over their entirety. Fluorspar frequently occurs with the barite as well as chert, varying amounts of iron oxide and minor quantities of sphalerite and galena. Laurence[60]

(60) R. A. Laurence, Origin of the Sweetwater, Tennessee, barite deposits, Economic Geology, Vol. 34, No. 2, March-April 1939. pp. 190-200.

believes the veins to be the source of the residual barite, and that they were "formed by ascending thermal waters; but whether there were magmatic or meteoric remains in doubt." Gordon [61] also proposes

(61) C. H. Gordon. op. cit., p. 56.

that the residual barite was derived from the veins in bedrock, but thinks that this vein material was deposited from meteoric waters which had obtained the barite from overlying rock. This barite is believed to have been precipitated as colloidal particles simultaneously with the deposition of the dolomitic rock from sea water.

The mining and beneficiation methods employed in the Sweetwater district are much the same as those used in Missouri. Chert and limonite are the principal impurities, with fluorspar occurring as crust on some of the barite. When the latter situation is encountered, the operation is usually abandoned because the separation of fluorspar and barite is too difficult. The chert is easily removed by gravity concentration and iron present in excess may be removed by magnetic separation after drying and fine crushing. The major tonnage of production from the Sweetwater district is utilized in glass and barium chemical manufacture. In the past, much of the barite was shipped to the eastern lithopone market.

Nevada

Many barite deposits are known to exist in Nevada, but only those in the northern part of the state are commercially significant. Production began in 1916 and although only a relatively small tonnage has been marketed since that date, a steady increase has ensued each year. Recent attention to the deposits in Nevada indicate that an important output may come from the state in future years.

With but one exception, all of Nevada's barite comes from an area in Lander and Eureka counties near Battle Mountain. The barite occurs as veins and as replacement deposits in both shale and limestone. According to Gianella [62] the largest production has been

(62) V. P. Gianella, Barite deposits of northern Nevada, AIME Technical Paper 1200, Mining Technology, July 1940. p. 296.

from the Nevada barite mine about 4½ miles southeast of Argenta siding. Here, the barite is a replacement of a gray limestone, with limestone, shale, some quartzite and conglomerate constituting the country rock. The color of the barite is dark gray to black and contains some chert nodules and bands of shale. The mining is by open pit methods, the ore being blasted from the country rock, loaded and trucked to the Southern Pacific Railroad at Argenta for shipment.

Other important deposits are located south of Slavin Canyon, 14 miles southeast of Battle Mountain, and at Bateman Canyon, 15 miles south of Battle Mountain. The deposit occurring in the former area is an 8 feet thick vein of dark barite, probably a replacement in limestone, overlain by 2 feet of black, carbonaceous shale. The ore is mined by open cut methods after removal of the shale and with only a small amount of sorting contains 90 to 94 per cent barium sulfate. The deposits in Bateman Canyon contain cream to white colored barite and is also a replacement in limestone. Little production has taken place, but considerable ore might be revealed after further development.[63]

(63) Ibid, p. 297.

Ginella thinks that the barite was deposited from rising hot waters similar to and probably contemporaneous with those responsible for the metallic ores occurring in the state.

California

The Division of Mines of California Department of Natural Resources reported that three barite mines were operating within the state in 1945, one each in Mariposa, Nevada and Plumas counties. The combined production reported from California for the years 1944-45 was 67,783 tons with a value of $409,825. It is believed that production has lessened considerably since 1946 because of reduced output of the most important mines located near El Portal in Mariposa County.

The mines near El Portal have been operated since 1927 by the Baroid Sales Division of the National Lead Company. An excellent description of the geology of the deposits and the operations in this area is given by Harding.[64] There are two distinct mineral-

(64) A. C. Harding, Ground barytes for weighting drilling muds, Engineering and Mining Journal, Vol. 142, No. 1, January 1941, pp. 33-36.

ized belts or zones which are parallel and are transversely cut by the westward flowing Merced river. The topography is rugged and has thus allowed entrance to the deposits with adits thereby excluding any shaft sinking. The barite bodies are replacements in limestone and it is believed that the source of the barium is at least indirectly connected with magmatic origin. According to Harding, the barium probably replaced the calcium in calcite forming barium carbonate or witherite and later introduction of the sulfate radical by meteoric waters converted a majority of the witherite to barite. Witherite occurs in some quantity and has been mined in this district. The mining, although originally done by quarrying and mill-holing, in recent years has been restricted to underground operations. The mining method used is shrinkage stoping. Two mines are operated by National Lead; the South Barium mine which is south of the river and the Carbonate Hill mine on the north side. The latter is the source of all the witherite which has been produced. A plentiful supply of water is obtained from the Merced River for use in the mill, which is located on the north bank near the portal of Carbonate Hill mine. The ore mined in the South Barium mine is transported 3000 feet across the steep river valley to the mill by an aerial tramway. Jig concentrating, grinding, dewatering and drying constitute the relatively simple flowsheet. One unusual feature of the milling process is a method of using a ball mill for not only grinding but also as a gravity concentrator. This has been described by Harding.[65]

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[65] A. C. Harding, Barite production in the United States. AIME Technical Publication No. 2414, Mining Technology, July 1948. p. 5.

"The ball mill is used as a gravity concentrator, a practice which originated at the El Portal plant and has been called 'selective grinding'. In theory the pulp density of the mill charge is maintained at 3.4 so that the lighter waste floats in the pulp and is discharged unground. The barite being softer, heavier and more friable is readily ground and a separation of ground barite and unground waste is effected by 3/16 in. and 30-mesh trommel screens attached to the discharge end of the mill. The bowl classifier is also in circuit with a 50-mesh trommel screen and all mill discharge coarser than 50-mesh is discarded from the circuit. Plant experience has shown that a better concentration can be effected by selective grinding than by jigs or tables."

Other barite deposits in California, only a few of which have produced even a minor tonnage, are described by Bradley. [66]

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[66] W. W. Bradley, Barite in California, AIME Transactions, 1931. pp. 170-176.

Arizona

Although increasing important tonnages of barite have produced in Arizona in recent years, the only information available concerning the deposits and the operation within the state is from the Minerals Yearbook of 1946, published in 1948 by the Bureau of Mines. The following information has been taken from this source.

Spasmodic shipments of barite have been made from Arizona in the past, the last year of any substantial activity being 1938. In 1946 a determined bid for business in the southwestern oil fields was made by a new firm, the Arizona Barite Company. The mine is at Coon Bluff, 22 miles northeast of Mesa, and the mill a short distance south of Mesa on the Southern Pacific Railway. The ore is mined underground, crushed and wet-ground to 200-mesh with no attempt at concentration other than some hand sorting in the mine. The final product analyzes 94 per cent barium sulfate with a specific gravity of 4.0 or better. Production is stated to be 100 tons a day. The ore occurs in a series of fissure veins in a volcanic conglomerate. In addition to the main vein, which is being worked, seven additional veins have been partly explored. The main lode is about 15 feet wide and 3,000 feet long and has been opened to a depth of 140 feet by a steeply inclined development shaft. The company expects to mine by shrinkage stoping when full-scale operations are reached.

Others

During the early years of the industry, several states in the Appalachian area were important producers. Virginia had the first output of barite and led all states in tonnage mined until surpassed by Missouri in the 1890's. North and South Carolina have both produced barite at intervals since the middle 1800's. There seems to be some hope of revival of the industry in the Carolinas as indicated by recent activity.[67] Alabama and Kentucky marketed barite

(67) E. C. Van Horn, New barite possibilities revealed in the Carolinas, Engineering and Mining Journal, Vol. 150, No. 1, January 1949. pp. 76-78.

from the early 1900's until 1924 and 1926 respectively.

A small amount of barite has been produced from Connecticut, Idaho, and Pennsylvania. Deposits are reported as occurring in Colorado, New Mexico, Washington and Wisconsin, although "little or no attempt has been made to exploit the deposits." (69)

(69) C. L. Harness and F. M. Barsigian, op. cit., p. 14.

RESERVES

The most specific information concerning the commercial barite reserves was given in public hearings before the Committee for Reciprocity Information, Tariff Commission, on January 20, 1947. The hearings were the result of requests for tariff reductions on barite by the Netherlands and Cuba, such reductions being opposed by domestic producers. A summary of the reserve figures presented at the hearings appears on pages 163 and 165 of the Minerals Yearbook of 1946.

According to Walter B. Hester of the National Lead Company, there is a total of 20,000,000 tons of barite reserves in Washington County Missouri. The national Lead Company and Magnet Cove Barium Corporation have together proved 9,000,000 tons of reserves in the Magnet Cove area of Arkansas. Only 50,000 tons were left at El Portal, California and it is believed that this operation has ceased mining. National Lead's Spanish mine in Nevada County, California had in 1947 estimated reserves of 200,000 tons, some of which might not be minable. At Battle Mountain, Nevada, the National Lead Company has blocked out three new deposits with estimated reserves of 2,500,000 tons. The position of the United States in regard to barite resources is probably better today than at any time during the past 10 years. According to the testimony given before the Committee for Reciprocity Information, about 40,000,000 tons of commercial grade barite have been blocked out, at least roughly, by producers. The writer believes that as the present deposits are worked out, other deposits now considered non-commercial will be opened for production; that is, if the demand for barite, especially for its use in drilling muds, continues at or near the level existant today.

SUMMARY

The utilization of ground barite as a weighting material in drilling fluids has greatly increased the importance of the mineral. Notwithstanding this fact, a considerable tonnage of barite continues to be employed annually for the production of lithopone and barium chemicals. Minor quantities are used as fillers in materials such as linoleum, rubber and paint and as a flux in the manufacture of glass. The barite output in the United States was 725,223 short tons in 1946.

Barite mining is active in three regions in the United States, listed as follows:

1. Southeastern - Georgia and Tennessee
2. Mid-continent - Arkansas and Missouri
3. Western - Arizona, Nevada and California

In 1946, Arkansas led in barite production, followed by Missouri, Georgia, Tennessee and California. Other states in the Southeastern region have marketed barite in the past and there exists the possibility of rejuvenation of the industry in several of these states.

The following modes of occurrence of barite are of commercial importance:

1. Residual barite in clays derived from the weathering of Cambro-Ordivician dolomites. (Missouri, Georgia and Tennessee)

2. Replacement deposits in shale. (Arkansas)

3. Replacement deposits in limestone. (Nevada and California)

4. Fissure veins in volcanic conglomerate. (Arizona)

Other types of deposits include veins and solution cavity fillings in dolomite, located in Georgia, Tennessee and Missouri. Such deposits, however, are not mined commercially at the present, although they might become important in future years.

Mining and milling of barite is relatively simple at most properties. The largest operations are at Magnet Cove, Arkansas where the National Lead Company and the Magnet Cove Barium Corporation produce ground barite for use in drilling muds. Here, and at one mill in Georgia, froth flotation is employed to recover the barite from associated minerals. The only underground operation of importance is in California, near El Portal. The mining of the residual deposits requires only a shallow depth of excavation which is accomplished by power shovels. The beneficiation of these latter deposits is affected by gravity concentration, principally with jigs and tables.

An increasing demand for barite and the establishing of a greater tonnage of reserves indicates a secure future for the industry. Progress is being made in mining and milling methods and in research directed toward a greater utilization of the mineral.

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VITA

James Byron Chaney was born July 22, 1926 at Van Buren, Arkansas. Elementary schooling was received at Wynn, Arkansas, Poplar Bluff, Missouri and Little Rock, Arkansas. He was graduated from Little Rock Senior High School in May, 1943. He attended Missouri School of Mines and Metallurgy from June, 1943 to September, 1944, at which time he left school before entering the Army in December of that year. While in the Army, he attended Oregon State College. After his discharge, he re-entered Missouri School of Mines and Metallurgy in September, 1946 and was graduated with a Bachelor of Science degree in Mining Engineering June 1, 1948.

During the summer months of 1947 and 1948, he worked for the Baroid Sales Division of the National Lead Company at Magnet Cove, Arkansas where he served in the engineering department.